ASSATEAGUE ECOLOGICAL STUDIES

NATURAL RESOURCES INSTITUTE • UNIVERSITY OF MARYLAND

FINAL REPORT

PART I: ENVIRONMENTAL INFORMATION

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Final Report

Part I. Environmental Information

Natural Resources Institute
University of Maryland
Contribution No. 446

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N. R. I. Contribution No. 446.
University of Maryland

PREFACE

This is the final report to the National Park Service by the Natural Resources Institute of the University of Maryland under Contract #14-10-5-950-36, Research at Assateague Island National Seashore.

The contract stipulated two objectives related to the Assateague Island National Seashore.

1. "Furnishing to the Service of adequate information on the biological populations of the marine environment adjacent to Assateague Island in order that the Service may respond properly to a proposal by the Corps of Engineers, U. S. Army, for dredging in the said area to obtain materials to replenish and stabilize the dunes on Assateague Island for erosion control purposes." (See Figure 1 for proposed borrow areas.)

2. "The furnishing to the Service of basic biological, geological and ecological information and understanding of the areas surrounding Assateague Island to facilitate Service management of the area and to increase public appreciation of this new National Seashore."

Our approach to satisfying these general objectives was to utilize as many different disciplines as possible within the budget framework. We focused them on basic studies which would have applicability in making the dredging decision and in providing as much information as possible as a basis for the preservation and management of the new National Seashore. Our study sections and approaches are as follows:

--Geology and Climatology. Our primary emphasis has been to interpret the geological history of Assateague Island and to compare its history with barrier islands immediately to the south to allow an understanding of the dynamic processes which have produced Assateague Island and which will modify its structure and existence in the future. This information, it is thought, will be greatly applicable to dredging decisions. In addition, we have made a survey and analysis of bottom types throughout Chincoteague Bay, putting particular emphasis on the proposed borrow areas (Figure 1). The climatology, sea dynamics and freshwater sources of Assateague Island have been described.

--Primary Productivity. There are three significant sources of primary production in Chincoteague Bay: the planktonic algae; the underwater rooted aquatic plants which are located primarily in the Assateague Shore; and the extensive spartina marshes which surround the Bay. Our intent was to determine yearly production rates in the three factions, thus being able to calculate the relative importance of each component to the Bay. From this approach, much basic information has become available, and estimates can also be made of probable damage from inshore dredging.

--Benthos. Originally the Park Service requested "ecosystem maps" of the marine environment. Our preliminary surveys indicated that the benthic component appeared to be a mosaic of species and perhaps groups of species which may or may not be related to environmental parameters. Our approach was to take extensive quantitative benthic samples throughout the Bay, particularly in the proposed borrow areas, and then by appropriate analyses identify species which appeared to form groups or communities. Then we attempted to relate the groups to environmental parameters. This project, we estimated, would give the best approximations of the relative importance of the Assateague inshore areas to the benthos. Particular attention was given to the commercially important hardshelled clam, determining its bay-wide distribution, its distribution in the proposed borrow areas, and the relationship of its occurrence to environmental parameters.

--Crustacea. A bay-wide survey was made of Chincoteague crustacea. The proposed borrow areas and their possible importance in crustacean life cycles were investigated.

--Finfish. A survey was made bay-wide in Chincoteague Bay. The possible use of the Assateague shallows as a finfish nursery area was investigated.

--Peripheral Study Areas. The original contract, in addition to outlining the two general purposes, suggested many specific areas to be investigated and reported upon. Among these, we were to identify unique natural areas on the Island and suggest means of their display, identify possible threats to the Assateague environment, describe the commercial fisheries, and compile a bibliography.

The final report is presented in three parts as follows:

I. The Environment of Assateague National Seashore - A compilation of all of the field and library research gathered during the course of this project.

II. Threats to the Assateague Environment - A discussion of research which bears on Chincoteague Bay dredging, insect control and land disturbance.

III. Assateague Study - A suggested Assateague land use plan offered as a supplement to our final report.

We hope that our final report will assist the Park Service in managing and preserving Assateague Island as an aesthetic resource.

ACKNOWLEDGMENTS

We, the project workers, wish to thank the personnel of the Park Service, especially Mr. Bertram Roberts, Mr. James W. Godbolt, and Mr. Harvey Wickware for their continuing aid throughout the project. The U. S. Bureau of Commercial Fisheries, Oxford, Maryland was most gracious in lending laboratory facilities at Franklin City for our primary productivity work. We express our appreciation to the Maryland Department of Chesapeake Bay Affairs for the use of their facilities at Ocean City. Finally, Dr. L. Eugene Cronin, the Director of the Natural Resources Institute, provided continuing encouragement and suggestions which were instrumental in allowing successful completion of the project.

PROJECT PERSONNEL

The following NRI resident staff and summer students have participated in this project.

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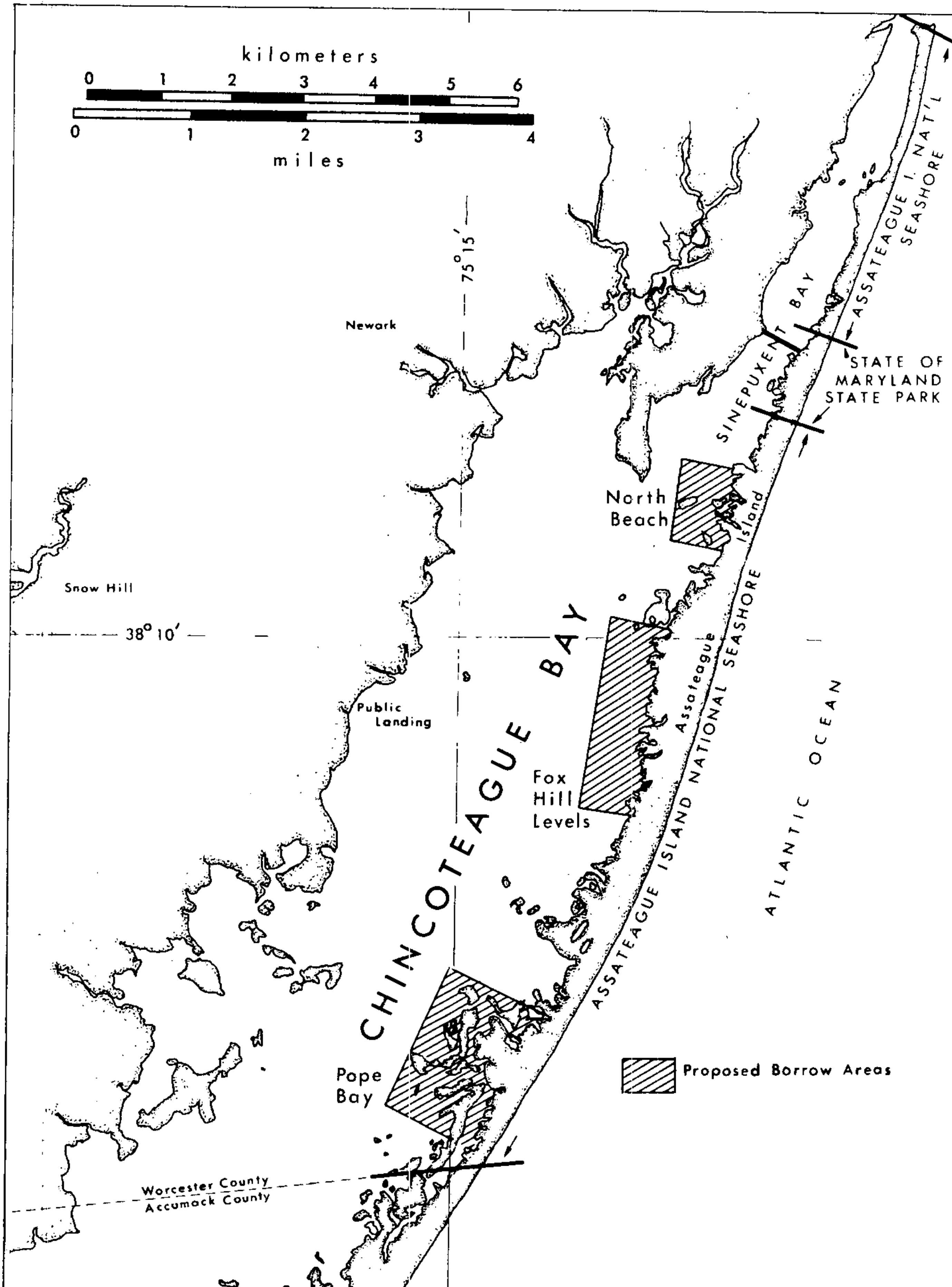

Figure 1. The Assateague Island National Seashore-Chincoteague Bay area showing proposed inshore sediment borrow areas.

geology

A. The Origin and Geological History of Assateague Island, Maryland and Virginia

Robert B. Biggs

INTRODUCTION

Barrier beaches and islands and their associated lagoons are features common to lowland coastlines where soft or unconsolidated sediments form the shore zone. They extend in an almost continuous chain along the U. S. Atlantic and Gulf coasts, from Long Island to Mexico. Barriers are beneficial to man, providing protection of the mainland from direct onslaught by the ocean, providing lagoons which serve as harbors and an environment for some life stages of waterfowl, fish, and shellfish, and providing sandy ocean beaches with vast recreational potential.

In this section of the report, I will attempt to review the theories on the origin of barriers, apply available data on Assateague and its lagoon to these theories, and suggest the origin and history of the island. I would like to acknowledge the assistance of Mr. Charles Bartberger, Mr. Robert Pellenbarg, Mr. Walter Boynton, Mr. Mark Odell, and Mr. David Tinker in performing the field work. Mr. William Lee of the Maryland State Roads Commission provided the subsurface data at Ocean City and Sandy Point. The illustrations were executed by Mrs. Frances Younger.

BACKGROUND

Shepard (1960) has enumerated several characteristics of barriers; (1) an outlying belt of sand separated from the mainland by a shallow body of water, (2) much greater length than width and, (3) straight or gently curving seaward margin in contrast to a crenulate lagoonal shoreline. The typical barrier has three major divisions; (1) an outer beach, (2) a belt of dunes and, (3) an inner flat or marsh. The area between the barrier and the mainland may vary in width from less than 1 mile to more than 20 miles, and consists of open bays, mud or sand flats, and marshes.

The barriers bordering the Delmarva Peninsula are of two distinct types. Fenwick and Assateague Islands (Fig. 1) are long, straight, or gently curving barriers while Wallops, Assawoman, Metomkin, Cedar, Parramore, Hog, and Cobb Islands form a segmented chain with numerous inlets. Data presented in Table 1 demonstrates the differences in geometric character among the islands. The barrier lagoons are also quite distinctive. The lagoons behind Fenwick and Assateague are open water with fringes of marsh and flats, while all of the lagoons to the south of Assateague are flats and marshes with open water restricted to deep, narrow channels and a few open bays.

Table 1

GEOMETRY OF DELMARVA BARRIERS AND LAGOONS

	km Length Island	km Max. Width Island	km Max. Width Lagoon	km^2 Total Area Lagoon	km^2 Area Open Water	km^2 Area Open Water / Area Lagoon	km^2 Area Flats & Marshes
Fenwick	31.15	1.75	5.39	77.95	55.94	.72	22.01
Assateague	57.96	4.52	11.59	428.9	320.12	.75	108.18
Wallops	9.04	2.51	4.02	21.93	3.54	.16	18.38
Assawoman	5.04	2.01	2.51	13.31	3.05	.23	10.25
Metomkin	10.54	1.38	3.52	30.35	15.77	.52	14.52
Cedar	9.43	3.76	5.54	47.94	9.09	.19	38.85
Parramore	13.07	3.52	7.73	95.18	18.07	.19	77.10
Hog	10.15	3.52	12.56	113.18	10.74	.09	102.43
Cobb	9.05	7.05	13.07	113.44	16.31	.14	97.31
				942.18	452.63		489.03
				(585.5 mi^2)	(281.3 mi^2)		(303.9 mi^2)

Geologists generally agree on two aspects of modern barriers, (1) that they are relatively young, and (2) that their formation has been associated with changes in the level of the sea with respect to the land. Figure 2 illustrates the changes in world sea level which have occurred as a result of continental glaciation. There have been four major glaciations during the past million years of the earth's history. With each one, precipitation fell on the land as snow and accumulated to great thicknesses (1-2 miles thick) covering large land areas (4,000,000 sq. miles in North America). Sea level fell as this large volume of water was tied up on the land, then rose as the glaciersmelted, causing the magnitude of oscillations observed in Figure 2. The latest glaciation, called the Wisconsin glacial stage, has left the most obvious imprint on our land surface today. The ice sheet extended as far south as Long Island and curved through North-Central Pennsylvania but did not extend onto the Delmarva Peninsula. During the maximum extent of Wisconsin glaciation 20,000 years ago, sea level fell to about -100m(-300 feet), leaving the Delmarva shoreline 100 km (62.14 miles) east of its present position. Most of the coastal and estuarine features of Delmarva shorelines have been formed since, and to an extent, as a result of the rise in sea level which has occurred during the last 20,000 years.

THEORIES ON THE FORMATION OF BARRIERS

Prior to 1960, the dominant theory on the origin of barriers was that they arose from the upward building of offshore sand bars. This theory was proposed by deBeaumont (1845) and involved the concept that waves approaching the shore stir sea-floor sediments which are deposited as a sand bar when the waves break. These sand bars grow above sea level to form barriers. However, Hoyt (1967) has reviewed the work of McKee and Sterrett (1961), who, using a wave tank, were able to produce offshore bars but in most cases could not make the bars grow to elevations above still-water level. Studies by Leontyen and Nickiforov (1966) suggest that the upward development of offshore bars stops as the water level is approached. Offshore bars are quite common off barrier islands but have not been observed to rise above sea level and create new barriers. Small, short-lived barriers have been formed from offshore bars but these cannot be compared to the major barriers. Hoyt (1967) has emphasized the most damaging evidence against the formation of barriers from the emergence of offshore bars. He has reasoned that the sequence of formation of barriers from offshore bars involves a gently sloping sea bottom and the formation of an offshore bar. At this stage in the development of a barrier, marine sediments and fauna would be deposited landward of the offshore bar. The bar then builds above sea level and the area toward the mainland becomes the lagoon. But beneath this lagoon there should be marine sediments and fauna deposited before the barrier was formed. However, Hoyt reviewed the literature and failed to find an instance when open marine sediments could be interpreted to have been formed landward of a bar which later developed into a barrier.

Gibert (1885) proposed that barriers could be formed by the lateral extension of spits. Material for the barrier could be provided by drift along the shore and the spit would be extended parallel to the flow of the longshore drift. Subsequent breaching of the spit could provide a chain of barrier islands. There is abundant evidence to support the supposition that spits do grow from headlands and are breached to form barriers but available data suggest that this occurs on a local scale and does not seem adequate to account for the major barrier systems. The same criticism concerning the predicted presence of marine sediments beneath the lagoon of bar-built barriers applies to the proposal by Gilbert.

Hoyt (1967) suggested a relatively simple hypothesis for the formation of barriers. He proposed that barrier formation is the product of a slowly rising sea level. Along sand beaches the wind will form dunes landward of the beach and swash of the surf will form a berm or beach ridge. By either wind or swash, a topographic ridge will form (Figure 3a). Then, as sea level rises, the ridge becomes a barrier island and the area landward of the ridge will be flooded to form a lagoon (Figure 3b). This hypothesis accounts for the absence of beach or open marine sediments landward of barriers, and is compatible with a general rise in sea level. In view of the available data, the hypothesis of Hoyt seems the most plausible to explain the origin of major barrier systems.

THE ORIGIN OF ASSATEAGUE

It would be difficult to study the origin of Assateague without considering its relation to the other barrier islands along the Delmarva Peninsula. I have already pointed out differences in the geometry of the islands and characteristics of the lagoons (Table 1). These differences suggest that the islands south of Assateague were formed in an essentially different manner, or are at a different stage of development from Assateague. It is difficult to believe that barrier islands 40 km apart on the same coast, subject to similar sea level changes and underlain by similar geologic formations, could have had a different origin. For the remainder of this report, I will assume that barriers off the Delmarva mainland formed and have been modified by similar processes.

Evidence from Borings and Wells

The sea level curves presented in Figure 4 have been derived from data on relative sea level changes along the east coast of the United States during the last 7,000 years. Most of the points on the curves were obtained in the following manner. Salt marshes form between high and low tide, and when buried by sediments as sea level rises, become peat layers. Samples of peat layers found in borings have been age dated by Carbon-14. Thus, the scientist has available the following information on the depth below present sea level at which the peat was found and the age of the peat. Therefore, he can estimate the position of some point between high and low tide at the dated time. The fact that different areas of the east coast demonstrate different submergence curves can be related to complicating factors. The range of the tide (the difference between high and low water) may vary from place to place. Areas where the tidal range is small may have salt marshes growing in a narrow interval near mean sea level, while marshes may be growing over a large vertical range in nearby areas where the tidal range is great. Another factor which may be responsible for the discrepancy between curves is the fact that the surface of the land in different areas may be rising or falling in addition to the general rise of sea level. The sea level curves (Figure 4) for Virginia (vicinity of Wachapreague) and New Jersey (vicinity of Brigantine) agree fairly closely from the present until about 4,500 years before the present (BP). Since Assateague lies between these barriers, it seems reasonable to utilize the curves from Virginia and New Jersey (Figure 4) to reconstruct the recent history of the island.

A drilling program was initiated to define the character of the materials which underlie Assateague Island and Chincoteague Bay. The locations of 26 exploratory borings are presented in Figure 5. Drilling logs and precise locations of the borings are described in the appendix. Several cross-sections of the Delmarva barriers have been constructed from data collected for bridge foundations (Sections A, B, E), one from a previous geologic investigation (Section F), and two from borings taken for this study (Sections C, D). These sections are located on Figure 1 and illustrated on Figure 6. Of particular note on the sections is the distribution of peat. Peat found in sections C, D, and F has been identified as salt marsh peat, and that found on sections A, B, and E is presumed to be salt marsh peat. The presence of salt marsh peat marks sea level at some previous time when sea level was lower than present, and also implies the presence of a barrier seaward of the peat location, since marshes grow only in lagoons. The presence of peat at depths of 7m-8.5m (21-26 ft) below mean sea level (MSL) in section A suggests that a barrier existed offshore from Ocean City, Maryland 4,500 years ago. Similar interpretation of the other sections results in the following minimum age of the barrier system; Section B, 5,000 years; Sec C, 4,500 years; Sec D, 5,000 years; Section E, 4,500 years; and Section F, 5,100 (the age determination on Section F by Newman and Munsart, 1968). Newman and Munsart, who bored Section F, found lagoonal sediments throughout the section above the peat. I have observed nothing above the peat layers in Sections C and D which would indicate open marine conditions. It is concluded that a series of barriers existed seaward of Delmarva mainland for at least the past 4,500-5,000 years.

Evidence from Existing Marshes

It is of considerable interest to note that the marsh deposits at the surface are thin in all of the sections and in most of the other borings described in the appendix. One would guess that the marshes should be underlain by thick deposits of peaty mud resulting from long accumulation of marsh deposits. The only explanation which can be offered is that the marshes have only recently begun to accumulate and that prior to marsh development the marsh areas of the lagoons were open water. Stuivier and Daddario (1963) dated the youngest basal peat (1,900 years BP) in the lagoon west of Atlantic City, New Jersey. It was found at a depth of approximately 3m, and Daddario (1961) noted salt marsh peat in that lagoon ranges from 1 m to 2 m thick. One would presume that accumulation of modern salt marsh began about 1,000 years BP along the New Jersey coast. Newman and Munsart (1968) found that Wachapreague marshes were only about 1 m thick and concluded that marsh formation began about 1,000 years BP in that area. Data from the Assateague boring program are consistent with these findings. Except for borings 24, 25, and 26, none of the rhizome layers are more than 0.5 m thick in the Chincoteague area that was sampled. Newman and Munsart suggested that marsh formation was inhibited until about 1,000 years BP, due to the rapid rise in relative sea level.

There are four significant marshy areas behind Assateague Island (Fig. 5); the Chincoteague area, the Johnson Bay area, the Middlemoor area, and the Tingles Island area. Most of the remaining marshes may be considered as fringing the bay without extending significantly into open water. The Johnson Bay, Middlemoor, and Tingles Island marshes are being eroded, while the Chincoteague marshes are stable or growing. The Johnson Bay marshes are associated with dune deposits, particularly on Mills Island, and are aligned with Sinepuxent Neck and Robins Marsh, both of which are thought to be Pleistocene beach ridges (Rasmussen and Slaughter, 1955). It is not difficult to believe that the Johnson Bay marshes are associated with a Pleistocene topographic high. The Chincoteague marshes are near one of the inlets to Chincoteague Bay. It is of some interest to note that the presence of inlets is associated with flats and marshes along this coast. Inlets are spaced at about 10 km (7 miles) intervals from Cobb Island to Wallops Island (Table 1); then, there is the unbroken run of 60 km (38 miles) from Chincoteague to Ocean City. The lagoons south of Chincoteague are filled with sediment-forming flats and marshes, while the Assateague lagoon is mostly open. Shepard (1960) has suggested that lagoonal sediments may be derived from the ocean by way of inlets, and perhaps that is why lagoons south of Assateague are filled. The Chincoteague marshes may be built on a "flat" formed by sediments entering the bay from the ocean. Alternately, relatively large variations in tidal amplitude may encourage the development and growth of the marsh. Proximity to inlets is highly correlated with tidal range 75 cm (30 in) at Chincoteague Pt., 30 cm (12 in) at Franklin City, and 12 cm (5 in) at Public Landing . Perhaps the influx of sediment, coupled with sufficient tidal range near inlets, promotes the development of flats and marshes. Two extensive marshes in Chincoteague Bay--Middlemoor and Tingles Island--are isolated from existing inlets. Historical accounts of former inlets (Truitt, 1968) along Assateague indicate two persistent inlets, one near North Beach and one near Green Run Bay (see Bartberger and Biggs, this report). These inlets would be located in the "right" position to have supplied sediment and tidal range to stimulate marsh development at Tingles Island and Middlemoor. Figure 7 illustrates the coastline in the Green Run Inlet area in 1850, and again in 1900. The persistence of marsh deposits in borings 24, 25, and 26 suggests that Green Run Inlet was open for a considerable time. On the other hand, the lack of marsh deposits beneath Tingles Island (Section C) would seem to indicate that North Beach Inlet was not open for long periods of time. Thus, I would hypothesize that the Chincoteague marsh is growing due to proximity to an inlet, and that Middlemoor and Tingles Island marshes are retrograding because the inlets that were associated with their formation have closed, thus decreasing the tidal range and cutting off the source of sediment to create new shoals for marsh encroachment.

A prominent feature of central Chincoteague Bay is a large shoal extending 5 km (3 miles) westward from Assateague, and topped by the Pirate Islands (Fig. 5). Sub-bottom data (Section D, Fig. 6) indicate that Pleistocene sediments lie at shallower depths beneath the Pirate Islands than anywhere else where borings were made. In fact, borings in the vicinity of the Pirate Islands are the only ones where we know with certainty that Pleistocene sediments were penetrated. Thus, the major shoal area aligned east-west across Chincoteague Bay seems to be the surface expression of a buried Pleistocene topographic high.

Major Lineations and Shoals

All of the barrier islands are oriented north-northeast with the exception of Fenwick Island, which sweeps in a smooth curve from north-northeast near Ocean City to north at the Maryland-Delaware border to north-northwest at Cape Henlopen (Fig. 1). Most of the major offshore shoals are aligned significantly more to the northeast than is the present coastline, with the exception of Wallops and Chincoteague Islands.

Beginning at Cedar Island, all of the barriers to the north form a smooth curve bending eastward and ending at Chincoteague (Fig. 1). Chincoteague Island exhibits numerous northeast trending dunes or beach ridges which are nipped off at the northern end of the island (Fig. 8). Apparently, Chincoteague was once a barrier island, and Assateague has been extended southward to "capture" the coastline. It is a historical fact that Assateague has been extended southward by the formation of the hooked spit, Fishing Point, since 1850 (Gawne, 1966), and there is little doubt that this southerly extension had been occurring before that time. It is interesting to extend to the north the arc formed by Cedar, Metomkin, Assawoman, Wallops, and Chincoteague Islands, because such an extension would predict an inlet at the northern tip of Chincoteague (perhaps that is why the dunes are nipped off at the northern end) and a barrier island extending northward to Green Run Inlet. Further extension of the arc to the northeast would pass just east of Great Gull Shoal (a submerged barrier?).

It seems reasonable to hypothesize that Assateague has coalesced from a series of smaller islands similar to the chain of barriers to the south. The lack of numerous inlets may be related to the offshore profile of the island, which is much steeper than the profiles further south. If the steep profile could accentuate longshore drift, then inlets might become clogged with sand, while the more gently sloping bottom further south would decrease the effects of longshore currents and allow inlets to remain open.

Other Evidences on the History of Delmarva Coast

Emery (1967) obtained a sample of peat dredged from a depth of 64 m (195 ft) about 80 km (50 mi) east of Wachapreague. The peat was a fresh water type with the following pollen types (by percent): fir (2%), spruce (12%), pine (8%), oak (4%), water lily (11%), and fern spores, spagnum spores, and arrowhead (63%). The Carbon-14 age of this sample was 13,500±350 years BP indicating that at that time the shelf off Delmarva contained fresh water ponds, grasslands and spruce forests. Emery has described ten such samples from the northeast shelf area. In addition, Emery has described American oyster shells dredged from similar depths. These oysters live in the shallow waters of estuaries or lagoons but their shells are found far out on the shelf. One sample of shell, taken about 20 km

(12.5 miles) south of the fresh water peat sample just described, was found found to be 9,600±600 years old and was taken from 64 m (195 ft) of water. This would indicate that about 13,500 years ago the area 80 km (50 miles) east of the present coastline was fresh water ponds and forests, and by 9,600 years ago had become an estuary. It is interesting to note that if the oysters did live in a bay or lagoon, there may have been a barrier seaward of that position.

CHRONOLOGICAL SUMMARY

Most of the evidence presented is equivocal, and I have attempted below to put it together to suggest a probable sequence. It is not difficult to imagine that others could put the same data together in a different way. As new information becomes available, modification or revision of the sequence may be necessary.

From about 20,000 years BP to the present, sea level has been rising at a decreasing rate. At 13,500 years BP,the present shelf was composed of fresh water ponds, grasslands, and perhaps spruce forests. The coast was at least 80 km (50 miles) offshore from its present position. By 9,500 years BP, sea level had risen to that position 90 km offshore. There is no evidence from this region as to the sequence of events from 9,500 years BP to about 5,000 years BP. The depths at which salt marsh peats have been formed suggest that there was a barrier chain seaward off the present coastline at 5,000 years BP when sea level was about 9 m (27 ft) below its present level. We cannot say that barriers were in existence from the period before 5,000 years BP, but they could have been. Those present after 5,000 years BP have sheltered the mainland ever since, because there seem to be no open marine sediments beneath the present lagoons or barriers. The offshore shoals (Blackfish Bank, Winter Quarter, Great Gull, etc.) may have comprised the barrier chain, but there is no evidence to support that supposition. Assuming that the base of the peat beneath the marshes in the Middlemoor area marked the development of Green Run Inlet (elevation -4.2 m, age derived from Wachapreague curve, 2,700 years BP), then Assateague was at least two islands from that time until Green Run closed by 1900. The dunes on Chincoteague suggest that the island once faced the ocean, that the dunes were nipped off on the northern end by an inlet, and that the southern end of Assateague has captured the coastline from Chincoteague.

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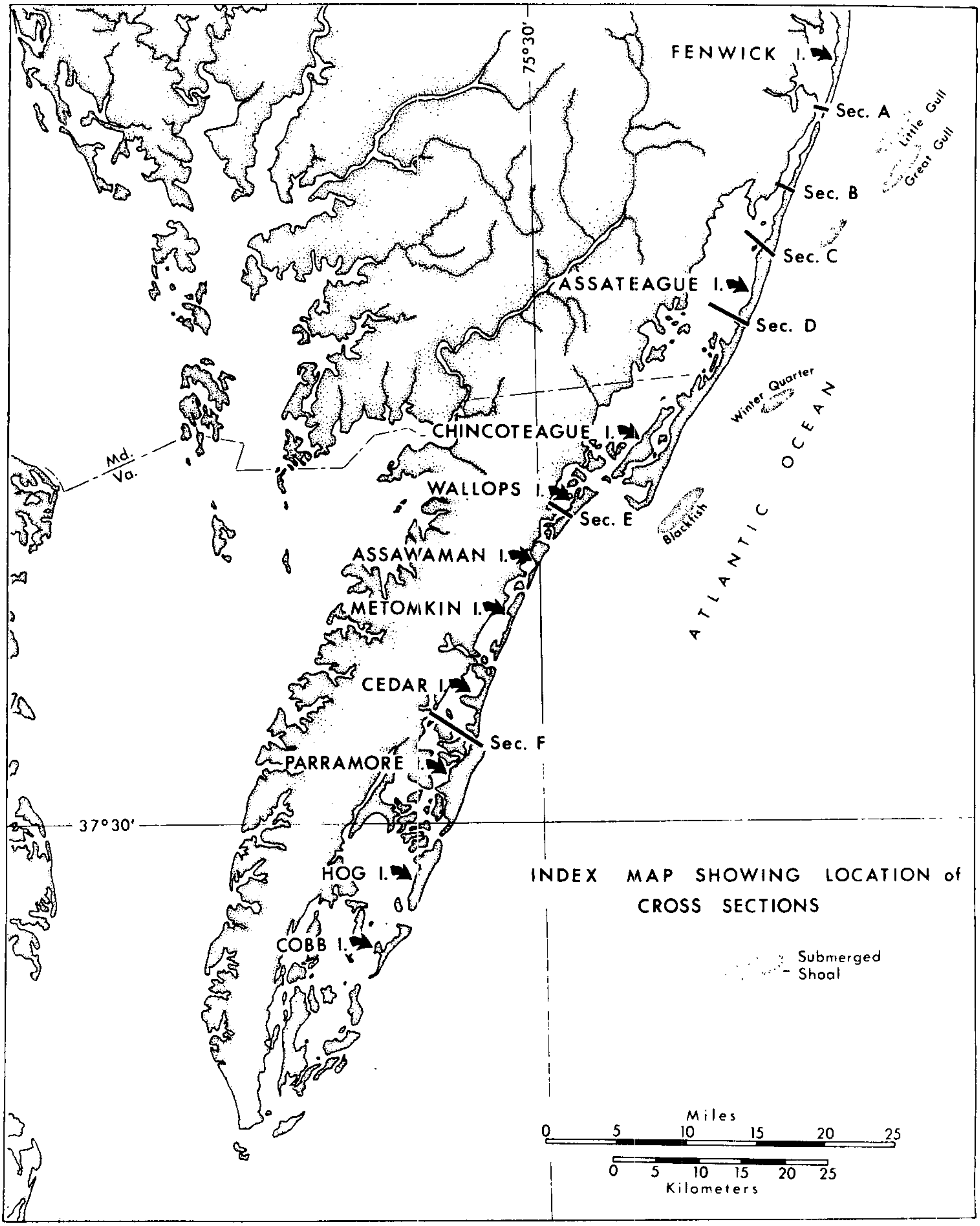

Figure 1. Area map illustrating Delmarva barriers, major shoals, and location of cross-sections discussed in this report.

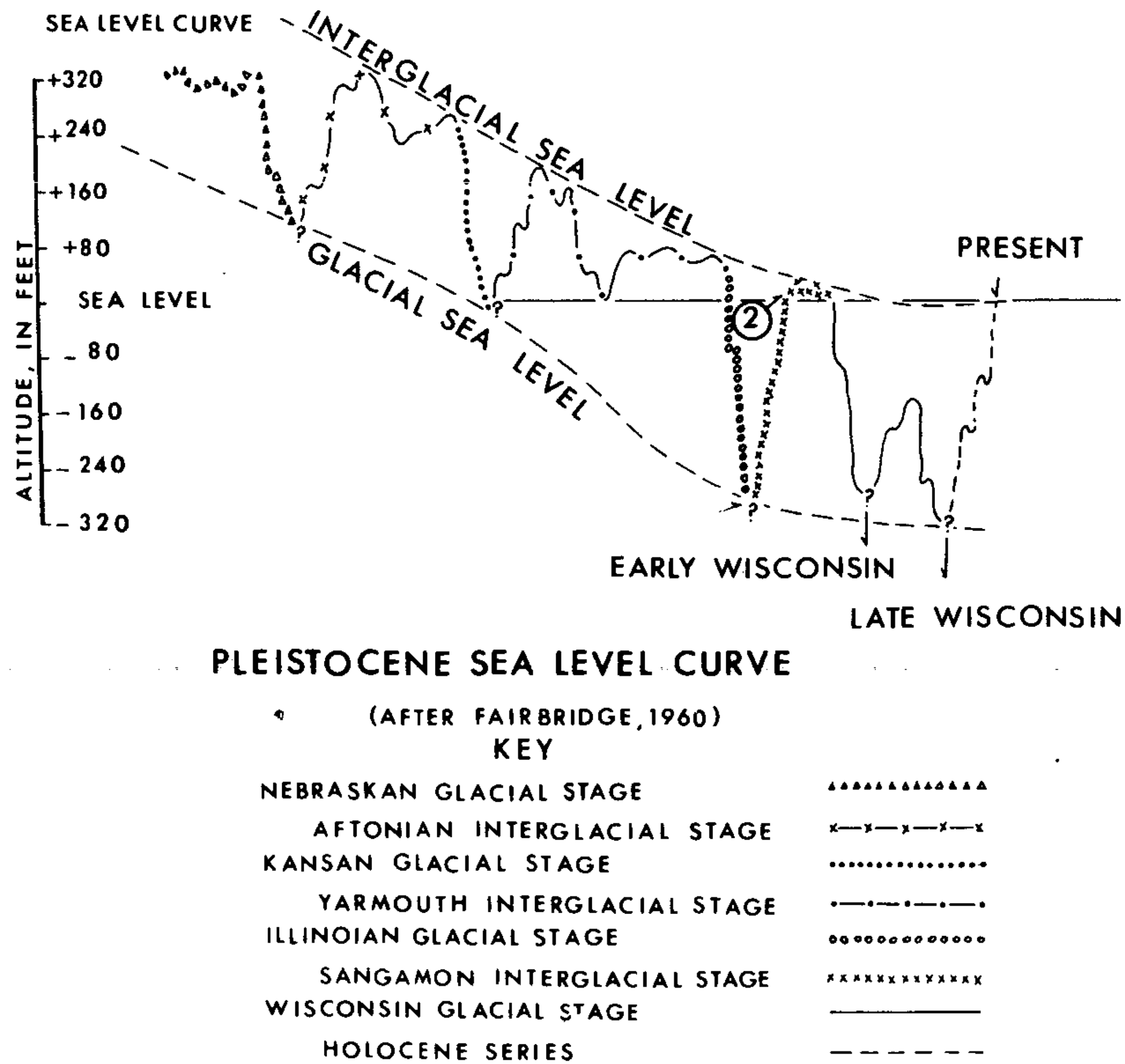

Figure 2. Variation in the level of the sea during the Pleistocene and Holocene (after Fairbridge, 1960).

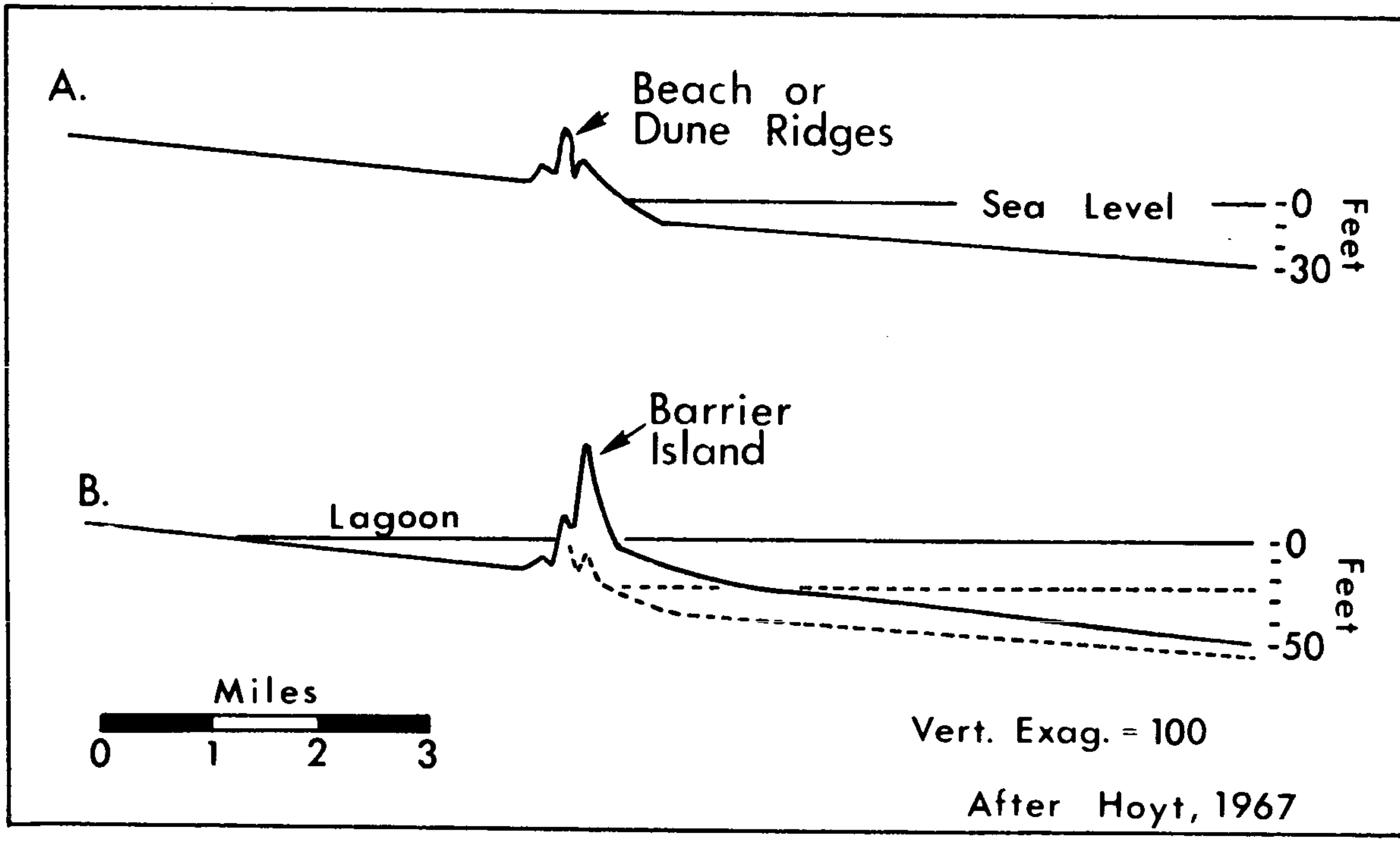

Figure 3. Development of beach or dune ridge (A), followed by rising sea level with development of barrier and lagoon (B).

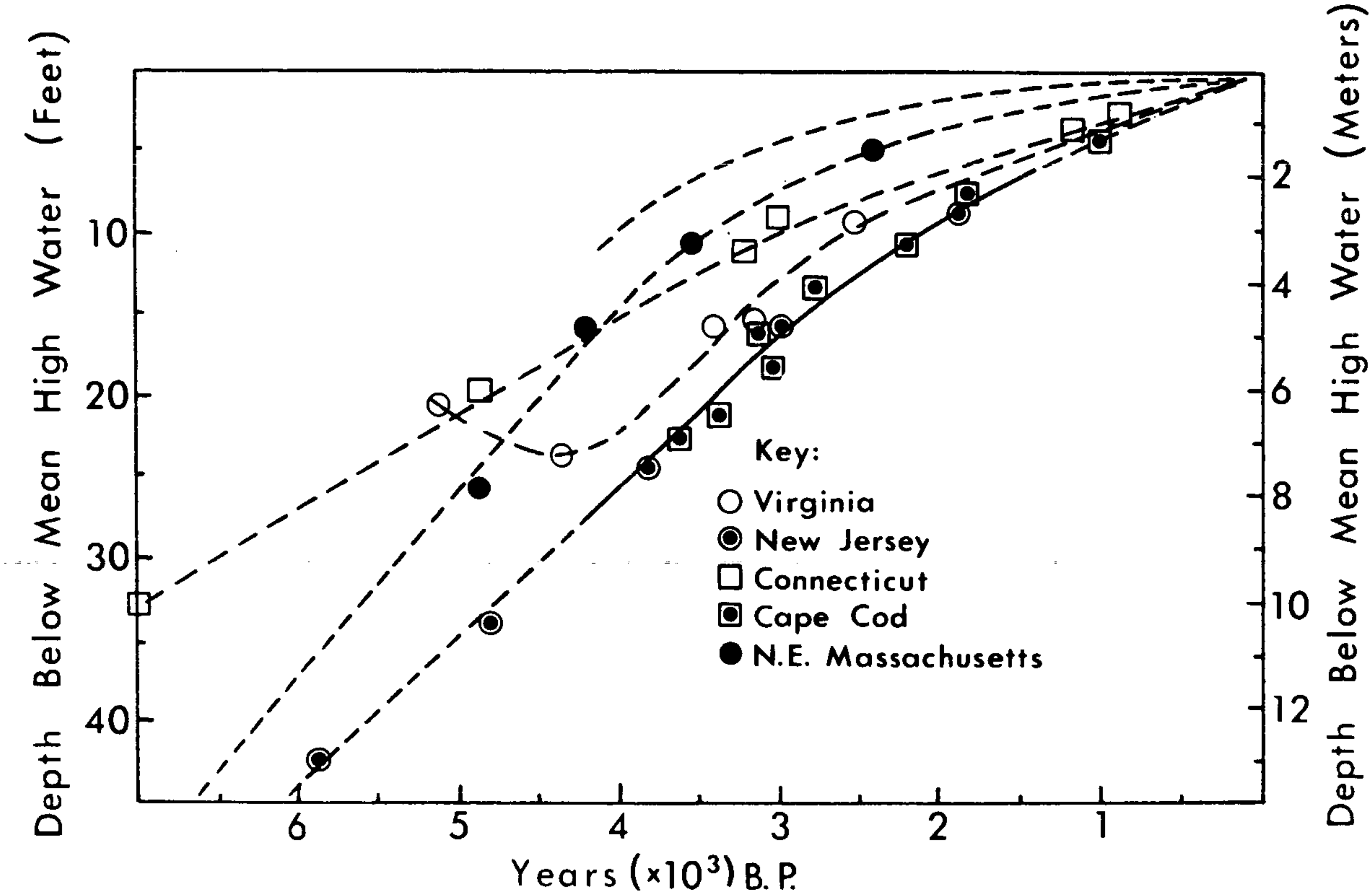

Figure 4. Holocene sea-level curves for the east coast (Newman and Munsart, 1968).

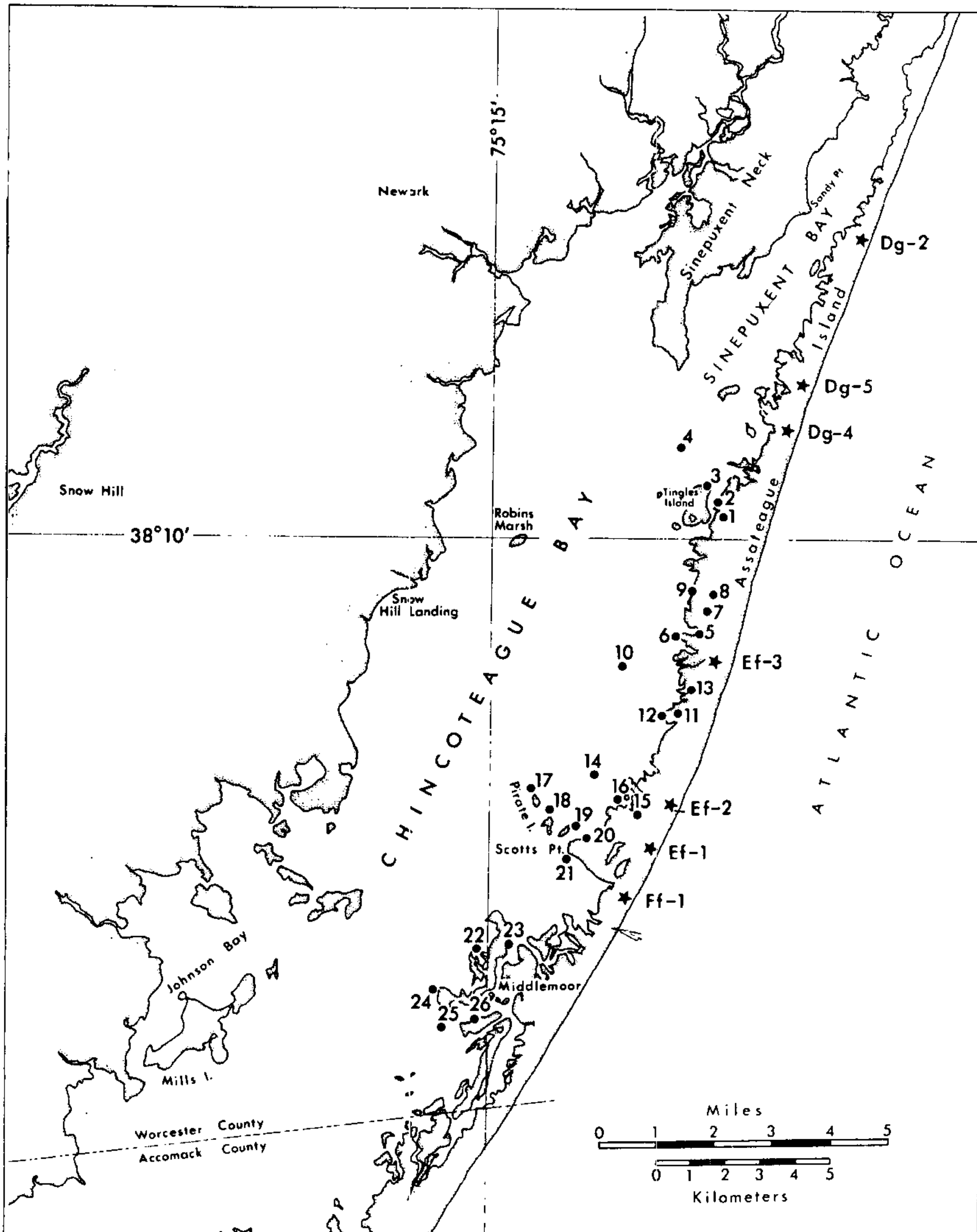

Figure 5. Location of borings from this study (circles) and from available well logs (stars).

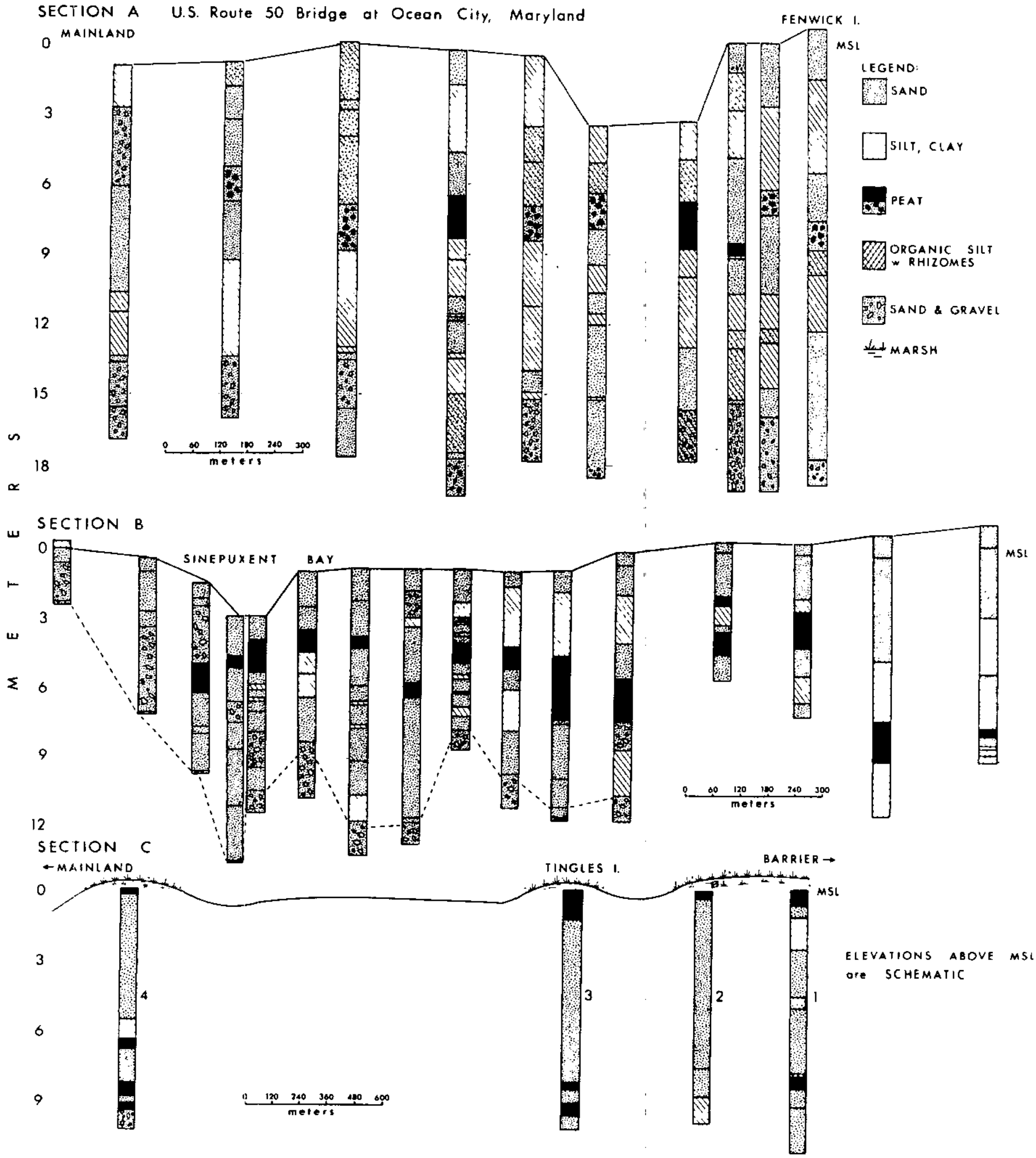

Figure 6. Cross Sections of the barrier-lagoon. Data for Sections A and B from Maryland State Roads Commission; for Section E, from NASA; for Section F, from Newman and Munsart.

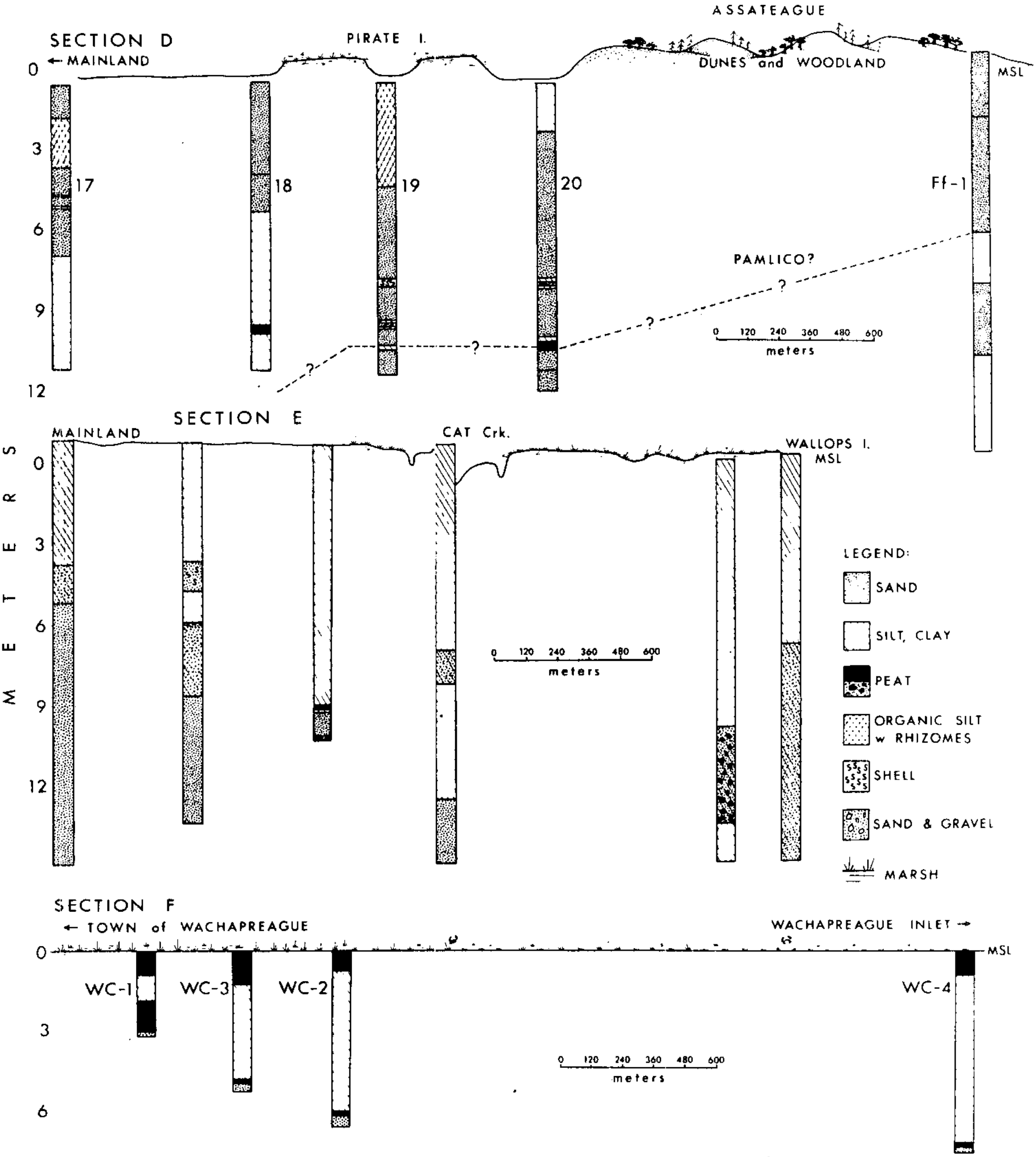

Figure 6 (continued). Cross Sections of the Barrier-lagoon. Data for Sections A and B from Maryland State Roads Commission; for Section E, from NASA; for Section F, from Newman and Munsart.

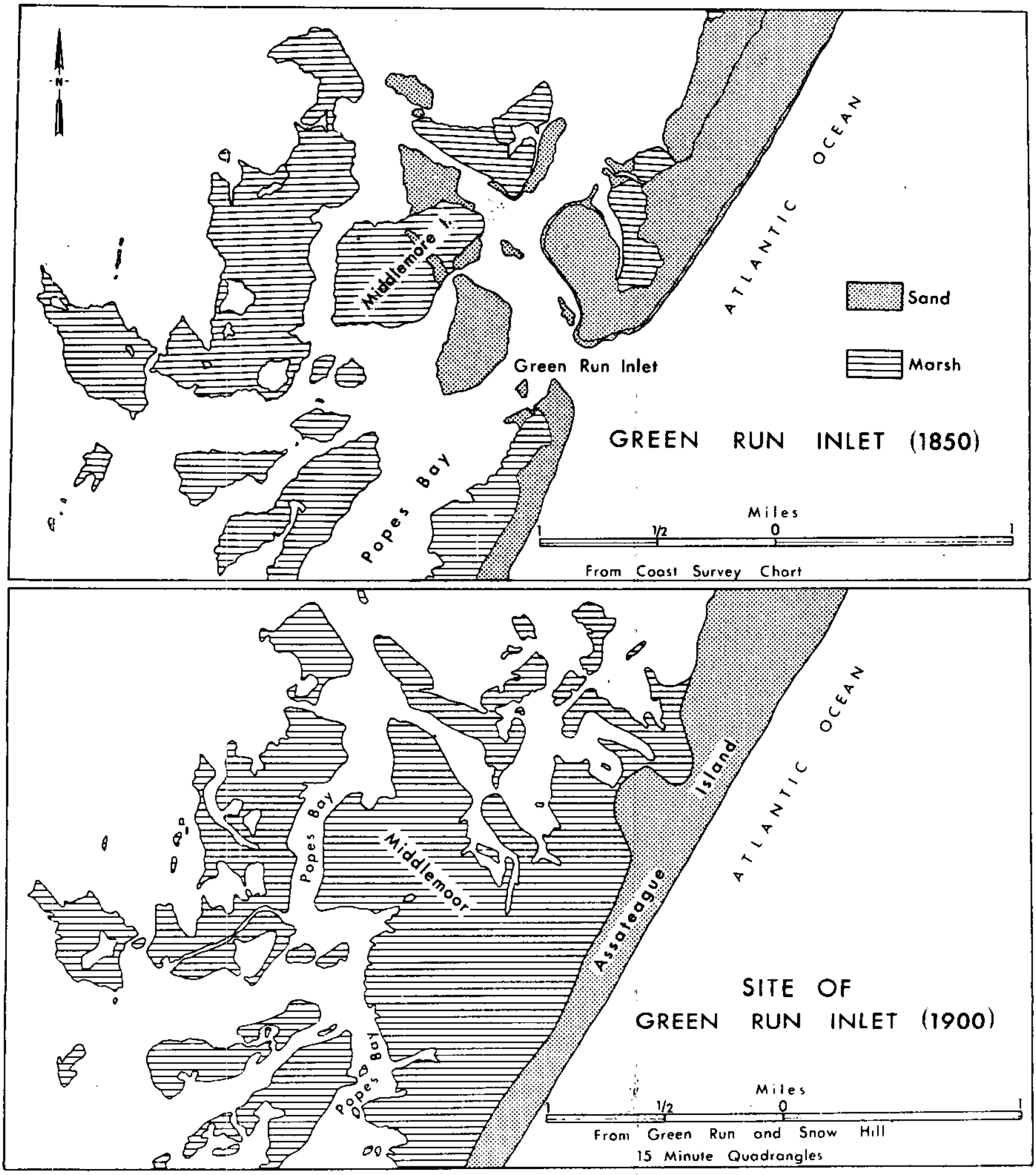

Figure 7. Historical record of development of Middlemoor and closing of Green Run Inlet (after Gaune, 1966).

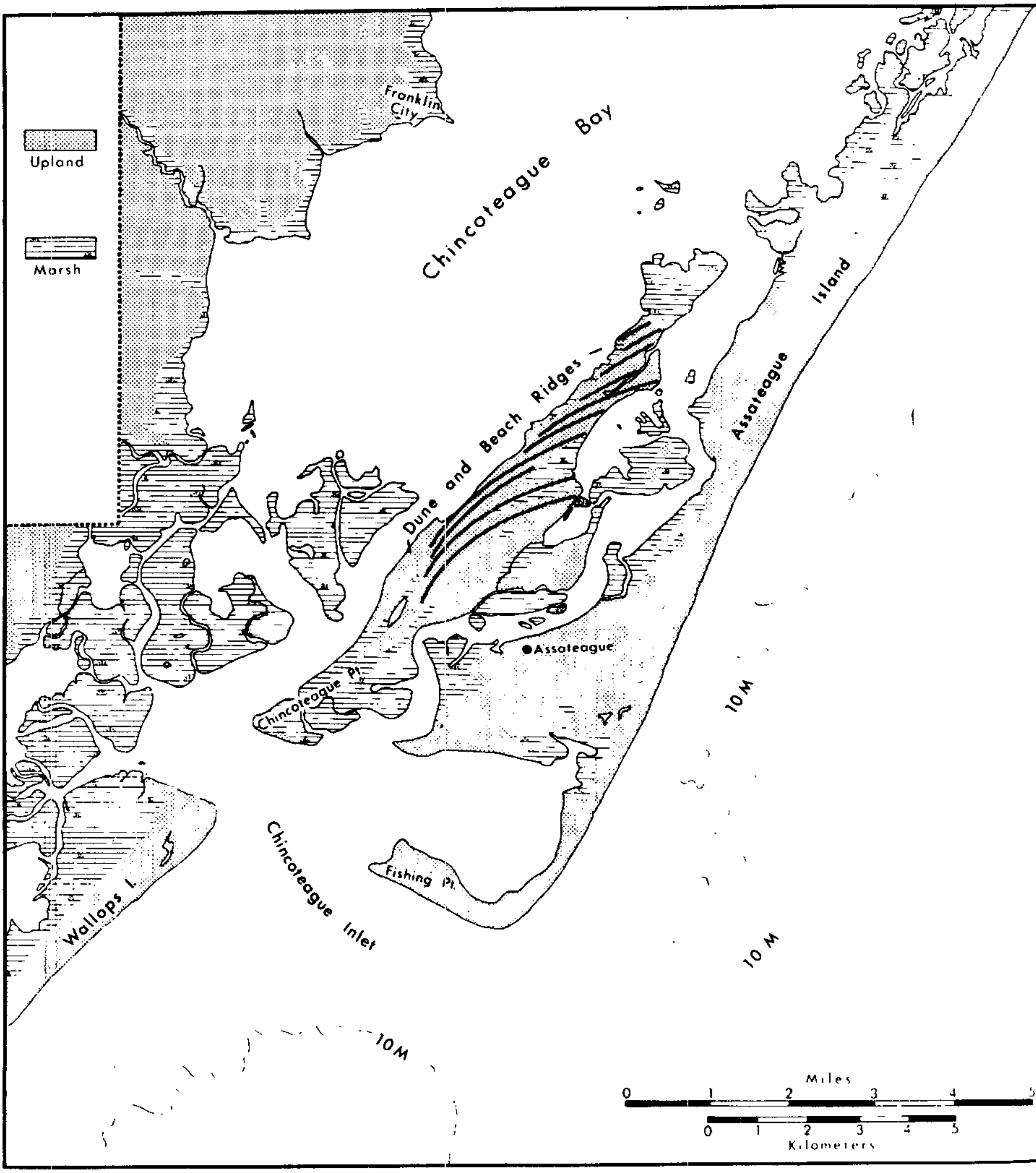

Figure 8. Axes of dune and beach ridges on Chincoteague Island.

ORIGIN AND HISTORY OF ASSATEAGUE ISLAND

APPENDIX

Showing Locations and Logs of Test Borings

(depths below sea level in meters)

Boring #1 38° 10' 19", 75° 10' 39"

0- .5	marsh
.5- 1.0	gray fine sand
1.0- 2.5	gray silt
2.5- 4.5	gray fine sand with shell
4.5- 5.0	silt with rhizomes
5.0- 8.0	gray green fine sand with trace silt
8.0- 8.2	gray silt with rhizomes
8.2- 8.5	peat
8.5- 9.2	gray green medium sand with peat fragments
9.2- 9.7	gray medium sand
9.7-12.0	gray silty fine sand

Boring #2 38° 10' 31", 75° 10' 47"

0. - .2	marsh
0.2- 3.0	gray fine sand
3.0- 7.7	gray silty sand, woody material at 5.7 m
7.7- 8.7	gray coarse sand with trace silt
8.7-10.0	gray silt, trace fine sand

Boring #3 38° 10' 43", 75° 11' 17"

0. - .5	marsh
0.5- 6.0	gray medium sand
6.0- 8.2	gray silty fine sand
8.2- 8.5	peat
8.5- 9.0	gray medium sand with organic fragments
9.0- 9.5	peat
9.5-10.2	gray medium sand with organic fragments

Boring #4 38° 11' 38", 75° 11' 44"

0. - .2	marsh
0.2- 6.0	gray silty fine sand
6.0- 6.2	gray sandy silt
6.2- 6.7	peat
6.7- 8.2	gray silty fine sand
8.2- 8.7	peat
8.7- 9.0	gray fine sand with organic fragments
9.0- 9.2	peat
9.2-10.2	gray silty medium sand with pebbles

Boring #5 38° 08' 35", 75° 11' 03"

0 - .5	marsh
0.5- 6.5	gray medium to fine sand

Boring #6 38° 08' 38", 75° 11' 27"

0- .5	marsh
0.5- 2.0	gray silty medium sand
2.0- 4.2	gray silty medium sand with shell
4.2- 8.5	gray silty fine sand with organic fragments

Boring #7 38° 08' 51", 75° 11' 01"

0- .5	marsh
0.5- 1.2	gray medium to fine sand
1.2- 3.5	gray silt
3.5- 4.2	gray silty fine sand with shell
4.2- 5.0	gray medium to fine sand
5.0- 6.5	gray silt with rhizomes
6.5- 7.0	gray silty medium to fine sand
7.0- 8.5	gray green sandy silt
8.5-10.0	medium to fine gray sand with shell and organics

Boring #8 38° 09' 01", 75° 10' 56"

0- .5	marsh
0.5- 7.7	gray fine sand with shell

Boring #9 38° 09' 12", 75° 11' 15"

0- .2	marsh
.2- .7	gray silt
.7- 6.5	gray silty fine sand with woody fragments
6.5- 7.5	gray fine sand

Boring #10 38° 08' 13", 75° 12' 22"

0- .2	marsh
.2- 1.0	gray silty sand
1.0- 1.2	peat
1.2- 4.5	gray sandy silt
4.5- 8.5	gray silty fine sand
8.5- 9.5	gray medium sand

Boring #11 38° 07' 29", 75° 11' 25"

0- .5	water
.5- 3.2	gray medium to fine sand
3.2- 6.5	gray silty fine sand
6.5- 7.2	oyster shells
7.2- 8.0	gray silty fine sand

Boring #12 38° 07' 25", 75° 11' 48"

0- .2	water
.2- 4.5	gray silty fine sand with wood fragments
4.5- 8.2	gray sandy silt with oyster shells

Boring #13 38° 07' 44", 75° 11' 18"

0- .5	water
.5- 3.2	gray fine to medium sand
3.2- 5.5	gray fine to medium sand with pebbles
5.5- 6.0	gray sandy silt

Boring #14 38° 06' 53", 75° 12' 50"

0- 1.0	water
1.0- 7.7	gray medium to fine silty sand with thin silt layers

Boring #15 38° 06' 12", 75° 11' 11"

0- .5	water
.5- 4.7	green silty clay with shell
4.7- 8.0	gray silty fine sand
8.0- 8.5	shell
8.5-10.0	green silty clay with trace fine sand

Boring #16 38° 06' 19", 75° 12' 30"

0- .5	water
.5- 4.0	gray green silty clay with trace fine sand
4.0- 8.2	gray silty fine sand
8.2-10.0	gray green silt with trace fine sand

Boring #17 38° 06' 30", 75° 14' 09"

0- .5	water
.5- 1.7	gray fine sand
1.7- 3.7	gray silt with rhizomes
3.7- 4.7	fine gray sand
4.7- 5.2	thin layers silt and woody fragments
5.2- 7.0	gray fine sand
7.0-11.5	gray silt with trace fine sand and shell

Boring #18 38° 06' 06", 75° 14' 05"

0- .5	water
.5- 5.7	gray fine sand with trace silt
5.7- 9.5	gray silt with trace fine sand and shell
9.5- 9.7	peat
9.7-11.2	gray silt with trace fine sand and shell

Boring #19 38° 05' 56", 75° 13' 36"

0- .5	water
.5- 5.5	gray sandy silt with rhizomes
5.5-10.2	silty medium to fine sand with shell
10.2-10.7	green silt with shell
10.7-11.5	tan to bright green fine sand

Boring #20 38° 05' 43", 75° 13' 14"

0- .5	water
.5- 2.2	gray silt with trace fine sand
2.2-10.0	gray silty fine sand with scattered shells
10.0-10.2	peat
10.2-11.2	green silty sand
11.2-12.0	bright green silty fine sand

Boring #21 38° 05' 21", 75° 13' 24"

0- .5	water
.5- 4.0	gray fine sand with shell
4.0- 4.2	shell layer
4.2-11.0	gray sandy silt with shell

Boring #22 38° 03' 47", 75° 14' 41"

0- .5	water
.5- 7.0	gray to green silt with trace fine sand and oyster shells
7.0-12.5	gray silty fine sand with shell

Boring #23 38° 03' 58", 75° 15' 10"

0- .7	water
.7- 4.0	gray silty fine sand
4.0- 7.0	gray sandy silt with rhizomes
7.0- 7.2	shell layer
7.2- 9.7	gray sandy silt with rhizomes
9.7-10.0	peat
10.0-10.5	gray sandy silt with rhizomes

Boring #24 38° 03' 21", 75° 16' 00"

0- .5	water
.5- 3.0	gray organic silt with rhizomes
3.0- 3.2	shell
3.2- 6.2	gray organic silt with shell
6.2- 9.2	gray silty medium to fine sand

Boring #25 38° 03' 04", 75° 15' 40"

0- .5	water
.5- 2.7	gray organic silt with rhizomes
2.7- 4.2	gray silt with shell
4.2- 7.2	clean gray fine sand
7.2-14.0	gray silty fine sand
14.0-14.2	peat

Boring #26 38° 02' 54", 75° 15' 22"

0. - .5	water
.5- 1.0	gray silty sand
1.0- 4.0	gray organic silt with rhizomes
4.0- 4.2	shell layer
4.2- 6.5	gray organic silt with rhizomes
6.5- 9.0	gray silt with shell
9.0-11.5	gray silty fine sand

B. Background Environmental Data on Assateague and Surrounding Areas

Robert Pellenbarg
and
Robert B. Biggs

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WEATHER OF THE MARYLAND-VIRGINIA BARRIER ISLAND COMPLEX

Weather data for the barrier islands are scarce. With the exception of the intensive settlements of Chincoteague Island, Virginia and Ocean City, Maryland, the barrier islands are generally uninhabited. Even the abovementioned communities lack the facilities to have made extensive weather observations over a period of years, and to have had such observations reported. Thus, one must extrapolate data available for points inland since even the mainland on the western shore of Chincoteague Bay is sparsely populated. Recently, limited data for Assateague Island State Park became available as it was brought under increasing development (see tabulated lists which follow).

Information regarding insolation of the area is entirely lacking. Somewhat cloudy conditions are not uncommon, with visibility limited to less than 5 miles for up to between 20 and 40% of the time(Mariner's Log, May, 1962). A governmental report during the time of eclipse of March, 1970 indicated that,in March, the lower eastern shore of Maryland can expect relatively clear weather 34% of the time. Clear weather is quite common on the barrier islands in summer, of course.

Due to the islands' Atlantic exposure and low profile with lack of cover, they are frequently buffeted by high winds, especially during storms or when storms are in the area. Winds are relatively stronger in the autumn, particularly because of the chance of hurricanes coming up the coast to the Assateague area. Wind direction at such times is highly erratic; wind speed, also, is extremely variable. During the summer, the classic land-sea breeze system of air flow for any coastal region is in evidence with generally gentle winds blowing onshore during the day, and offshore at night. Days of complete calm can occur during the summer, as can violent winds associated with such storms as northeasters. Wave direction data available for Ocean City, Maryland indicate that during the year winds generally blow from within about 10 degrees of southeast, assuming that most surface waves are wind-generated. High winds of an irregular directional nature are common in the area during the summer because of the incidence of thunderstorm activity.

Temperatures on all points of the island are moderated by the proximity of the ocean and Chincoteague Bay. Thus, extensive periods of bitter cold or tropic heat are not often encountered as at some inland locations, though it is well to note that during the winter of 1969-1970 the area was cold enough for a long period of time so that the Chincoteague Bay froze over to a degree unprecedented in recent years. Summer heat is moderated by the constant sea breezes blowing across the island.

Rainfall in the area is remarkably evenly distributed during the year, averaging about 3 inches a month. The influence of a subtropical climate is evident, with a slightly increased monthly average (to about 4 inches) during the high sun months of June, July, and August. Snow is not uncommon for the islands, but actual accumulation is scant because of the lack of cover on the islands; any snowfall promptly melts even though exposed to a weak winter sun.

Table 1.

Temperature in °F

Location:	J	F	M	A	M	J	J	A	S	O	N	D
Assateague State Park								77.2	70.8	63.4	51.5	37.0
Blackwater Refuge	30.4	32.0	46.8	54.6	61.9	73.6	76.6	75.9	66.0	60.4	50.5	37.2
Cape Henry, Virginia	36.6	35.6	50.7	55.9	64.9	74.9	78.1	79.5	71.8	64.3	54.1	
Chincoteague Refuge	34.2	33.9	46.1	54.3	61.9	72.4	78.0	78.0	70.4	62.9	51.9	58.7

Averages, in order as above: (, 55.5, , 56.9)

Rainfall, in inches. Data for 1968.

	J	F	M	A	M	J	J	A	S	O	N	D
Assateague State Park								1.79	2.86	1.90	2.66	2.8
Blackwater Refuge	2.96	.47	5.06	1.26	4.12	5.07	3.19	4.50	2.04	1.90	3.65	2.1
Cape Henry, Virginia	2.44	.98	3.21	2.83	1.16	2.35	4.07	1.48	1.32	3.39	1.74	2.72
Chincoteague Refuge	2.46	1.86	5.38	1.43	2.98	4.60	4.26	1.99	2.57	3.21	3.92	

Totals: (, 36.35, , 27.89, , 36.95)

Freeze Data, 1968 First Fall Minimum of:

	32° or below	28° or below	24° or below	20° or below	16° or below
Assateague State Park	11-21	12-8	12-10	12-10	12-10
Blackwater Refuge	10-31	10-31	12-7	12-10	12-11
Cape Henry, Virginia	-	-	-	-	-
Chincoteague Refuge	11-21	12-8	12-10	12-10	none

Last

	16° or below	20° or below	24° or below	28° or below	32° or below
Assateague State Park	-	-	-	-	-
Blackwater Refuge	2-27	3-8	3-8	3-14	4-12
Cape Henry, Virginia	none	2-12	2-27	3-4	3-15
Chincoteague Refuge	2-22	2-22	3-14	3-15	4-7

Data for Snow Hill over an extended period of time were in a separate list.

Above information from ESSA Climatological Data, Annual Summary for Maryland, Delaware, and Virginia, 1968.

Table 2.

	Average Temperature (°C)*	Average Precipitation (cm)*
	Snow Hill, Md.	Snow Hill, Md.
January	3.4	10.0
February	3.7	8.7
March	7.1	11.8
April	12.5	9.2
May	17.9	7.3
June	22.6	9.7
July	24.8	13.0
August	24.0	13.7
September	20.7	11.5
October	14.9	9.9
November	9.2	9.0
December	4.0	8.6

*Average based on period 1931-1960.

TIDES, CURRENTS, AND SEASWELL OF THE EASTERN MARYLAND-VIRGINIA SHORE

Tides

A major fraction of the geography of Maryland and Virginia eastern shore is influencedby water--the Atlantic Ocean, Chincoteague Bay, Sinepuxent Bay, and various small rivers and streams. The large volumes of water, whether salt or fresh, may be characterized by several movements which are caused by a variety of natural forces. Thus, tides, currents, and seaswell may be usefully employed in describing various naturally occurring movements in oceanic bodies of water such as the eastern shore bays, the ocean, and surface drainages which empty into these extensive bodies of water.

Tides are a direct manifestation of the fluid nature of water on the earth, and the gravitational influence of the sun and moon on this fluid mass. Thus, water is able to flow toward the sun and moon, being attracted by the gravitational forces of these massive bodies, and tending to pile up under these celestial bodies. However, the earth rotates under its thin covering film of water, and dry land can alternately approach a mass of water being attracted to the sun or moon, causing tides to rise; or move away from the mass of water, causing a drop in tides. As the moon orbits the earth, the moon's gravitational influence adds to and then opposes that of the sun, thus causing a periodic flux in the height of tides at any given location. As indicated by a glance at the following tide graphs for points on the Maryland-Virginia eastern shore, the more unrestricted a body of water, the greater the changes in tides to be observed. Thus, tides are much higher in the open ocean and at Ocean City, which is connected relatively directly with the ocean, than in the virtually enclosed Chincoteague Bay.

Currents

An extensive study of the oceanic currents along Assateague Island was undertaken over a period of nineteen months in 1963-1964. The Virginia Institute of Marine Science investigated both the surface and bottom currents of the Atlantic Ocean from near Ocean City, Maryland to near Cape Hatteras, North Carolina using air-dropped uninstrumented drift bottles for surface currents and sea-bed drifters for bottom measurements. One major reason for this study was to seek data to test the hypothesized existence of a general onshore bottom current into the Chesapeake Bay. Menhaden larvae, hatched at sea, were found in large numbers in the Chesapeake Bay and, presumably, reached that body of water as drifting planktonic organisms (Harrison, 1967). The study confirmed the existence of a net onshore current as a means of transporting menhaden larvae into the Bay.

The VIMS study indicated an overall onshore drift of surface water in the Atlantic Ocean (see Fig. 1) although anomalies were observed. During the winter, there is a net offshore wind pattern and some offshore currents were observed. The VIMS investigators failed to recover any drift bottles released in December, 1963; presumably, all were carried to sea by a combination of offshore winds and currents (Harrison, 1967), (see Fig. 2).

There are several major river systems such as the Susquehanna, Potomac, and Delaware emptying fresh water into the area of the study.

One characteristic of fresh or brackish water,such as discharged by the Chesapeake Bay, is that it remains fairly discrete and fails to mix readily with more saline water such as found in the ocean. Thus, as indicated by the drift of bottles near the Virginia shore in Fig. I, a coast-hugging current seems to be generated by the discharge of Chesapeake Bay. The nature of the drift of this Bay water, i.e., toward Cape Hatteras,would indicate that little, if any, influences the Assateague Island area.

In shallow Atlantic coastal areas off Assateague Island, by mid-April (Harrison, 1967) the waters become rapidly stratified from intensive insolation. Very little mixing occurs between layers of this thermally stratified water. The summer onshore currents are a particularly well-contained surface phenomenon. While surface currents are generally onshore, the entire water mass has a small northerly drift, perhaps due to the influence of the nearby Gulf Stream (Harrison, 1967). On the other hand, the bottom waters drift westerly to southwesterly nearing Cape Hatteras (Harrison, 1967).

While Chincoteague Bay is indeed directly linked to the Atlantic Ocean at the inlets of Ocean City and Chincoteague, one finds currents in its waters largely independent of nontidal oceanic currents. Indeed, one may describe the Bay as somewhat stagnant. The water is murky with suspended matter, and it becomes intensely heated and stratified during the summer. There is a net water loss via evaporation from this Bay, with ocean water making up a good part of the loss of volume due to the lack of sizeable fresh water runoff from the nearby mainland. The currents of Chincoteague Bay are generally tidal in nature, with water flowing slowly away from the inlets at Ocean City and Chincoteague Island as the tide rises. Net outflow of water from the Bay through processes other than evaporation is hard to establish and low in volume. Total water movements in the Bay are such that daily water exchange between the Bay and outside sources have been estimated at 7½% (Pritchard, 1960).

Waves

Whenever the air above a body of water moves, waves are created on the surface. The entire range from tiny ripples to mountainous breakers can occur, depending on whether a breeze or a hurricane is passing over a given body of water. Likewise, a passing ship, a diving bird, or an undersea earthquake may cause a disturbance in the water which will manifest itself and dissipate itself as waves or seaswell.

Table 3.

Data for the occurrence of heavy seas are commonly provided by observers aboard ships at sea. Such a source provided the data presented below for the Atlantic Ocean just off Assateague coast.

Time of year	Sea Height			
	5 ft. and up	8 ft. and up	12 ft. and up	20 ft. and up
February	30%	10%	5%	1%
May	10%	5%	1%	very rare
August	10%	3%	1%	very rare
November	30%	10%	5%	2%

See also Fig. 3.

Table 4. Surf Statistics for Ocean City, Maryland Lifeboat Station for Period October, 1954 through December, 1957. (Data modified from Army Corps of Engineers Tech. Memorandum #108, November, 1958).

Date	Surf Height in Meters					Max. Ave. Min.	Calm	N	NE	E	SE	S	SW	W	NW
	0-.6	.6-1.3	1.3-1.9	1.9-3.0	3.0-4.3										
1954															
Oct.	11	80	7	2		13.5 9.4 6.0		29	11	14	35	11			
Nov.	22	76	2			14.5 8.8 6.0		2	13	24	45	16			
Dec.	49	42	8	1		13.5 10.5 6.0			25	7	19	49			
1955															
Jan.	33	65	2			14.8 10.3 6.3			3	57	40				
Feb.	17	80	3			13.5 10.6 6.8			34	5	53	8			
Mar.	28	65	7			13.0 10.5 8.0			6	20	48	26			
Apr.	21	74	5			17.0 10.8 7.0			44	7	42	7			
May	28	66	6			14.0 11.1 7.5			23.6	7.5	56.6	12.3			
June	27.2	55.6	8.3	6.1	2.8	14.0 10.8 6.0			13.9	6.7	55.5	23.9			
July	8.6	86.0	5.4			14.0 11.0 7.0			4.8	16.1	53.8	25.3			
Aug.	8.6	61.9	13.4	16.1		12.8 10.5 7.0			8.1	19.9	55.9	16.1			

Table 4 . (Cont.)

	SURF HEIGHT IN METERS							WAVE DIRECTION(%)							
	0-.6	.6-1.3	1.3-1.9	1.9-3.0	3.0-4.3	Max. Ave. Min.	Calm	N	Ne	E	SE	S	SW	W	NW
Sept.	12.2	77.8	6.7	2.2	1.1	12.5 10.5 8.2			62.3	3.3	34.4				
Oct.	31.2	47.5	4.3	7.0		15.5 10.7 6.0			13.4	22.3	48.1	16.2			
Nov.	35.0	56.1	8.9			12.7 10.8 9.0			15.6	15.6	45.0	73.8			
Dec.	14.6	85.4				15.2 11.6 8.5			54.2	9.0	36.8				
<u>1956</u> Jan.	29.0	46.8	11.3	12.9		13.2 11.2 8.5			68.8	19.9	11.5				
Feb.	14.4	65.5	1.1			17.8 12.1 10.5			40.2	8.0	45.4	6.4			
Mar.	32.0	73.5	4.5			13.0 11.9 10.0			45.1	9.7	25.8	19.4			
Apr.	34.1	50.4	8.3	6.7	0.5	13.4 12.5 8.1			35.5	2.8	28.9	32.8			
May	14.2	81.9	3.9			13.1 11.8 9.0			33.7	13.4	20.2	32.7			
June	27.0	73.0				13.4 11.9 7.5		0.6	14.0	15.7	44.7	25.0			
July	1.6	98.4				13.4 12.2 10.5			18.2	17.1	34.2	30.5			
Aug.	2.2	87.0	10.8			14.0 12.4 10.2			22.0	27.4	23.2	27.4			
Sept.		78.8	15.6	5.6		13.4 11.7 6.8			39.4	17.2	35.6	7.8			

Table 4. (Cont.)

	SURF HEIGHT IN METERS							WAVE DIRECTION(%)							
	0-.6	.5-1.3	1.3-1.9	1.9-3.0	3.0-4.3	Max. Ave. Min.	Calm	N	NE	E	SE	S	SW	W	NW
1956															
Oct.	1.6	54.8	38.8	4.8		15.2 10.5 6.2			59.1	19.9	21.0				
Nov.	30.9	65.6	4.4			17.1 12.8 8.5			19.4	20.0	30.6	30.0			
Dec.	17.7	80.7	1.6			14.4 12.7 11.0			12.4	19.9	52.1	15.6			
1957															
Jan.	5.4	87.1	7.5			13.5 12.6 10.5			19.9	8.1	66.1	5.9			
Feb.	9.6	69.6	20.8			15.0 12.7 8.2			33.9	20.8	41.7	3.6			
Mar.	12.9	80.6	6.5			13.5 11.5 8.0			48.9	31.2	19.9				
Apr.		92.8	7.2			14.5 11.8 9.2			6.7	36.1	53.3	3.9			
May	28.0	71.5	0.5			13.2 11.7 9.9			28.5	15.1	56.4				
June	9.4	73.3	17.3			13.0 11.3 9.2			11.1	31.7	49.4	7.8			
July	26.3	73.7				13.3 10.5 9.0				2.7	87.1	10.2			
Aug.	3	96	1			12.3 10.7 8.2			37	18	45				

Table 4. (Cont.)

	SURF HEIGHT IN METERS						WAVE DIRECTION								
	0-.6	.6-1.3	1.3-1.9	1.9-3.0	3.0-4.3	Max. Ave. Min.	Calm	N	NE	E	SE	S	SW	W	NW
1957															
Sept.		96	4			11.8 10.1 7.4			9	62	29				
Oct.	11	78	9	2		11.8 10.2 7.9			18	46	36				
Nov.	12	78	10			10.9 9.6 8.2			19	49	20	21			
Dec.	5	70	18	7		12.3 10.4 8.4			20	41	39				

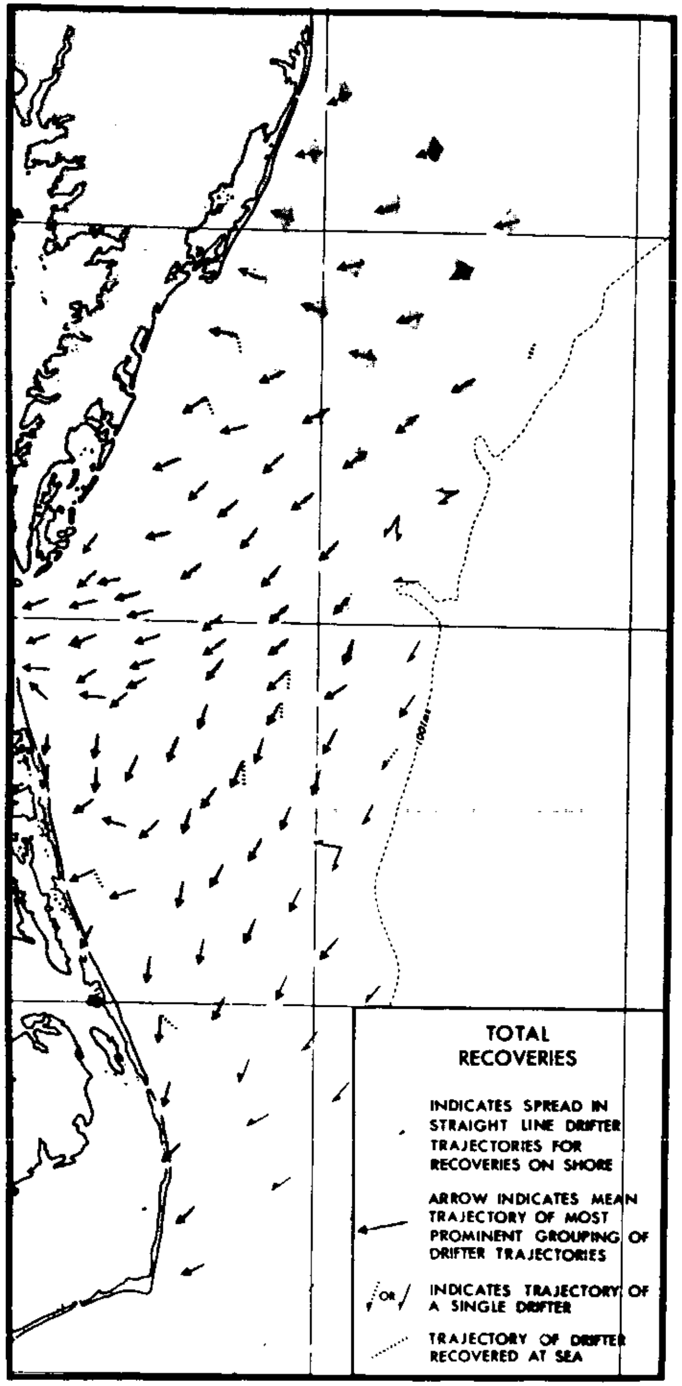

Figure 1. Surface Currents off Mid-Atlantic Barrier Islands (After Harrison and Norcross, 1967).

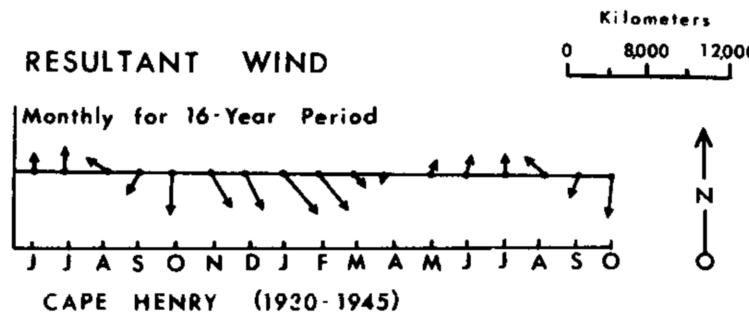

Figure 2. Yearly Wind Patterns for Cape Henry, Virginia (After Harrison and Norcross, 1967).

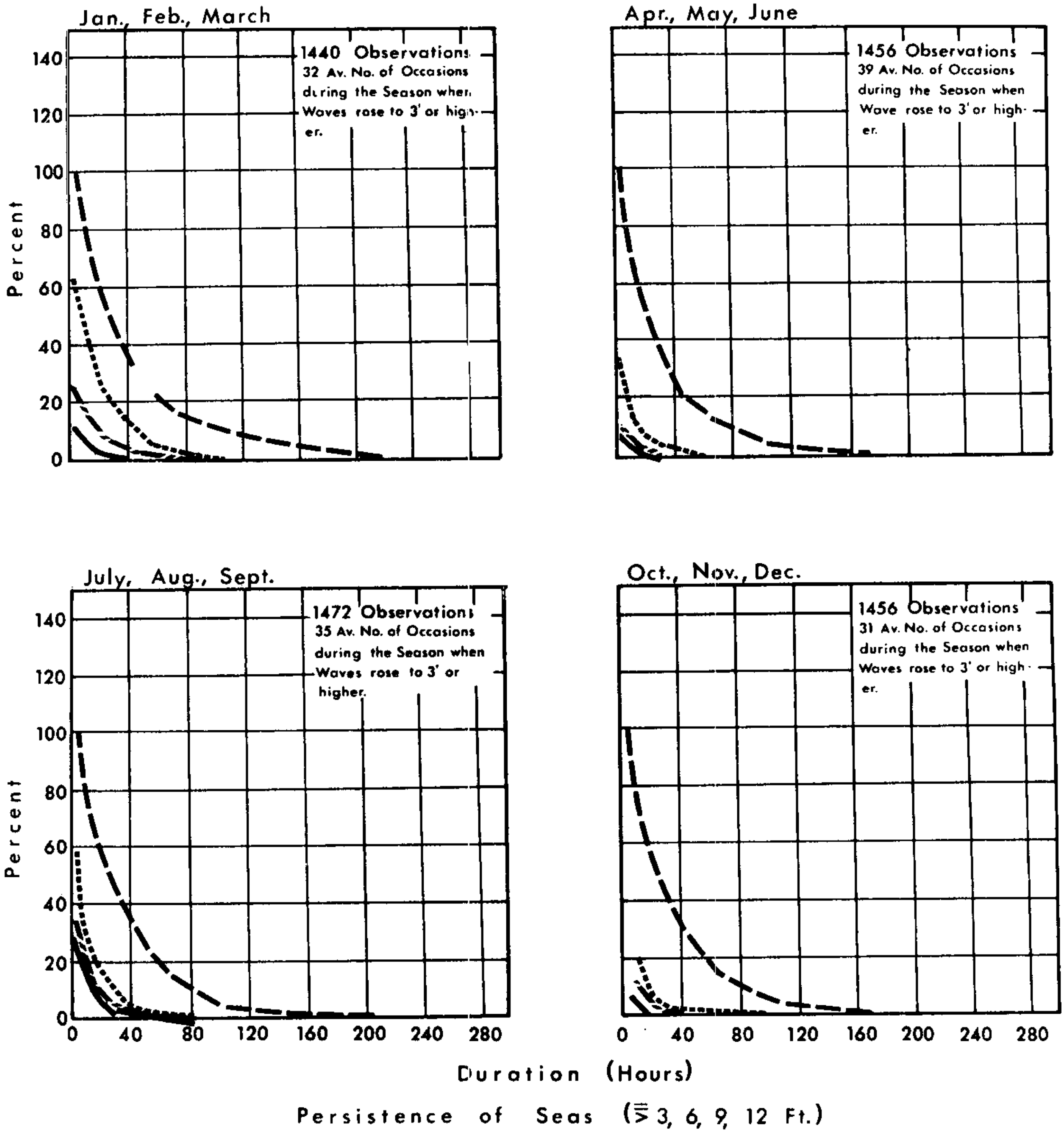

Figure 3. Representation of Seaswell off Mid-Atlantic Barrier Islands.

TIDES of OCEAN CITY Md., CHINCOTEAGUE BAY
(1970)

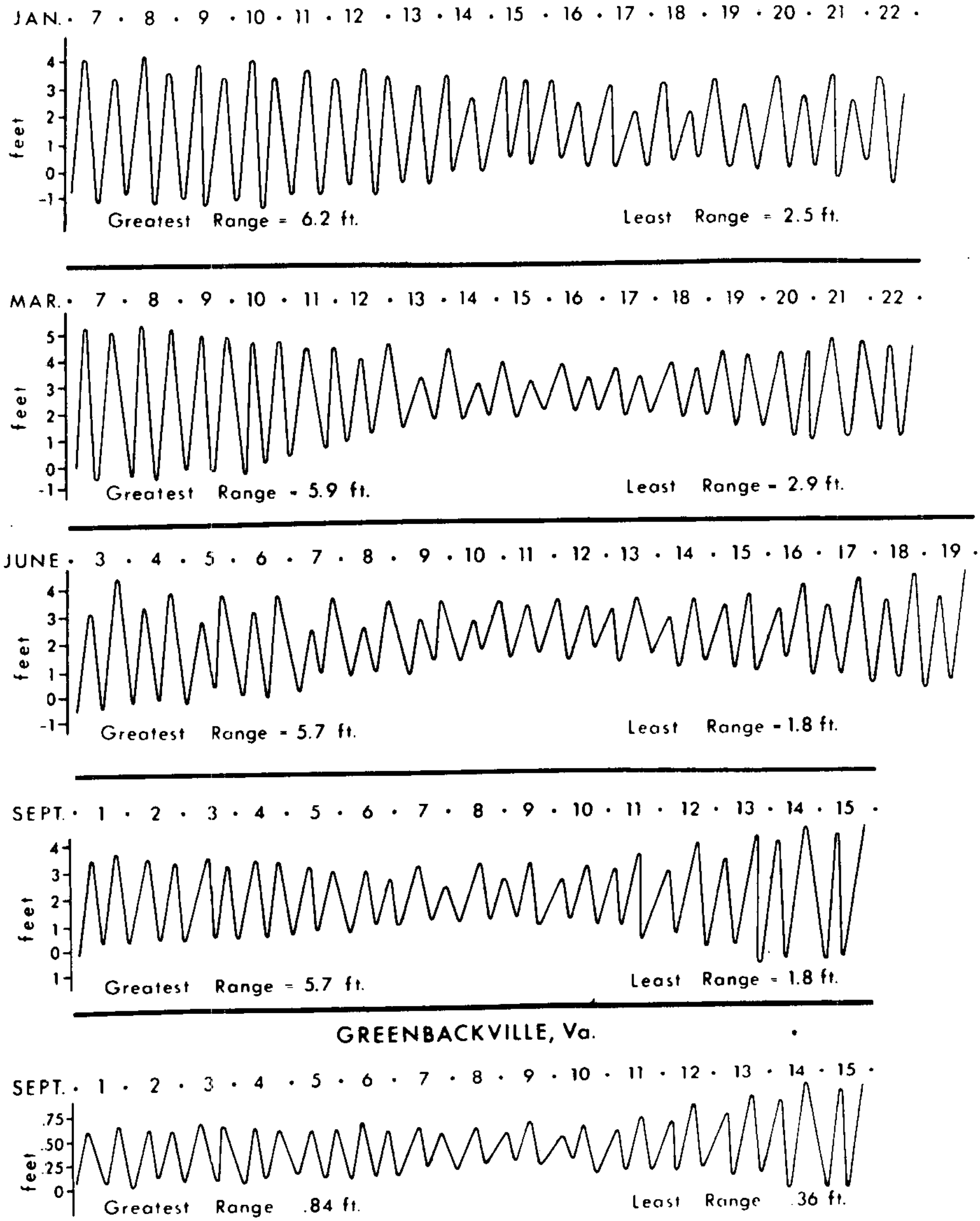

Figure 4.

GROUND WATER RESOURCES OF THE MARYLAND-VIRGINIA BARRIER ISLANDS

Since Maryland and Virginia's barrier islands are largely undeveloped except for the widely separated but unique developments of Ocean City, Maryland and Chincoteague, Virginia, extensive data on ground water supplies on the barrier islands are scarce. However, intensive development of ground water resources has occurred at Ocean City so that data for an Assateague-type island is available. Indeed, Ocean City relies solely on city-owned and-operated wells for its municipal water supply, indicating that considerable ground water is available. Information from the development and operation of this water supply may, with reasonable accuracy, be extended to points south on Assateague Island.

Various publications state that Maryland's three easternmost counties (Somerset, Wicomico, and Worcester), of which Assateague Island is a part, are in an area of relatively high yearly rainfall. Annual precipitation can average between 44 inches and 48 inches. One would expect this high yearly rainfall to serve as an excellent recharge source for the ground water supplies of the area. Of course, all the water falling on an area does not ultimately become ground water; large quantities run off and evaporate. Available data indicate that about 33% of yearly precipitation leaves the area as runoff in the Pocomoke River Basin alone (Darling, 1962). Evaporation, especially during the summer, claims another 15%, leaving about 50% of annual rainfall to serve as a source of ground water recharge in the tri-county area (Rasmussen, 1955). Now, from the small 60½ square mile area of the Pocomoke River Basin, 50% of the annual precipitation amounts to about 3 trillion, 300 million cubic feet of water available for ground water in the Pocomoke Basin alone. That such a large volume of ground water recharge can be accumulated is undoubtedly due to the generally highly porous, sandy, character of the Eastern Shore soils. Naturally, one would expect very little runoff to occur on the very sandy barrier islands; here, though most of the rainfall on the islands serves to recharge lenses of fresh water "floating" on salt water just under the surface of the islands, especially under the higher wooded sections, failing to penetrate to any great depth. These lenses are seldom, if ever, tapped because of the constant threat of salt water contamination of the resulting water supply. Indeed, one recent study indicates chloride-free water to be scarce in the island surface water supply (Dickinson College Study, 1967). However, shallow wells of 15 to 25 feet in depth do yield usable water for summer residents on Fenwick and Assateague barrier islands. These residents tap the lenses of fresh water under the larger dunes. Such resources can hardly be classed as dependable, though (Rasmussen, 1955).

Deep high-volume wells producing excellent fresh water without salt water contamination exist on the barrier islands at Ocean City. The small size and extreme porosity of the islands to sea water precludes recharge of the ground water supply from the rain falling on the islands. Where, then, do the large volumes of water obtainable come from? One must look to the mainland for the chief source of supply, as ground water deposited in the tri-county area and the coastal mainland of Virginia ultimately serves as the source of most of the available ground water on the barrier islands.

Usable ground water for the barrier islands is carried to them from the mainland by a series of aquifers underlying the entire area. An aquifer is simply a region of porous sediment enclosed by layers of relatively water-impervious sediments which stores water in the porous layer, the water being trapped in place by the nonporous layers. A major aquifer in the region is the Pocomoke aquifer, which consists of a medium to fine-grained sand enclosed by deposits of fine silt (Rasmussen, 1955). The intake area for this aquifer is indicated on Fig. 5. (Note: Water falling on this entire tri-county area does not usually feed this aquifer, as the intake area for this aquifer is rather small). It should be noted that Ocean City, Maryland obtains a great deal of its water supply from this aquifer at a depth of about 190 feet (see Fig. 5).

The Pocomoke aquifer, indeed, serves as a major water source for much of the tri-county area,and for good reasons. The aquifer is fairly close to the surface,porous, yields adequate water to numerous wells, and large volumes of water to a few. The water is of good quality with typical analysis being: silica 30 ppm, aluminum trace, iron 3 ppm, calcium 50 ppm, magnesium 10 ppm, sodium 25 ppm, bicarbonate 250 ppm, chloride 30 ppm, pH 7.2 (Rasmussen, 1955).

Ocean City has already found the Pocomoke aquifer to serve as an excellent water supply. Since this aquifer also underlies the barrier islands to the south, it would be safe to assume this aquifer to be a usable source of water there, too (see note on wells, Table 5, and Figure 7). That it could be a dependable source for large volumes of water on the barrier has been shown in various tests at Ocean City. For example, three wells in one of Ocean City's two well fields were pumped continuously at 127 gallons per minute for 19 hours. Water levels in the wells which had been allowed to stabilize (no pumping) for several days prior to the test, fell an average of only about 13 feet (Rasmussen, 1955).

The Manokin aquifer underlies this barrier island area also, and serves also as a water source for Ocean City. This aquifer, though, is deeper than the Pocomoke aquifer, and is made up of medium to fine-grained sands. The Manokin aquifer is nearest the surface in the vicinity of the Nanticoke River, being about 50 feet deep, and dips to about 300 feet under Assateague Island (Rasmussen, 1955). This aquifer opens into Chesapeake Bay in the west, and brackish water encroachment in the western part of the aquifer is a problem (see Fig. 6).

Water supply for the barrier islands seems quite adequate once it is developed, but extreme care must be exercised to avoid salt water contamination of fresh ground water, which is far from limitless on the islands. Indeed, there is reason to believe the existence of salt water--fresh water interface a few miles north of Ocean City (Rasmussen, 1955). Continued heavy pumping, especially if high volume wells on the barrier islands were developed, could draw this interface to the wells at Ocean City. The existence of salt water-fresh water interface seaward of the barrier islands is without question; its location is unknown, though. Excess removal of fresh water from the aquifers under the islands could prove hazardous again, with the constant threat of salt water contamination of the water supply. The Pocomoke aquifer as it appears under the Assateague area seems to be a good source of water. It should be able to provide all necessary water, if used carefully. Ocean City, serving a large community in the summer, finds it adequate.

TABLE 5. (refer to Fig. 8.)

Various wells have been driven on Assateague Island. Information regarding these wells may be summarized, as follows:

Well #	Date	Depth (ft.)	Dia. (in.)	Static Water Level (ft.)	Notes
1	1952	104	3		
2	1953	172	2	1.22	60^{o} water. Gave 20 gal/min for 8 hr with 5 ft water drop.
3	1953	228	2	12	Gave 12 gal/min 7 hr with 8 ft drop.
4	1953	167	2	.01	20 gal/min for 4 hr
5	1952	79	3		14 ft drawdown
6	1952	89	3		
7	1952	15(?)	2		Collected rainwater
8	1953	151	2	3	30 gal/min for 8 hr 5 ft dd
9	1953	150	2	1.43	25 gal/min for 8 hr 5 ft dd
10	1953	98	3		
11	1937	550			

(Data from Rasmussen, 1955).

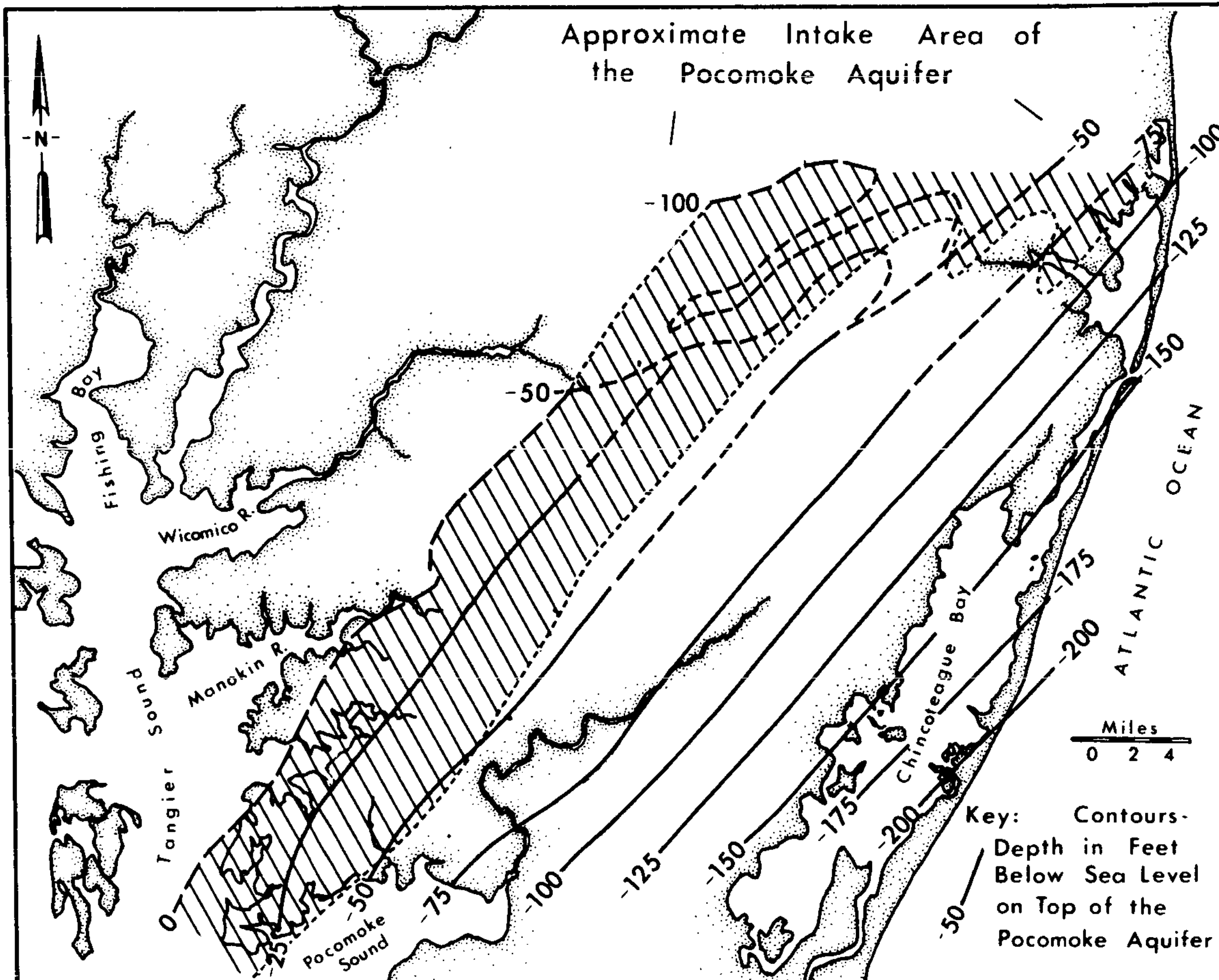

Figure 5. Approximate Intake Area of the Pocomoke Aquifer (After Rasmussen, 1955).

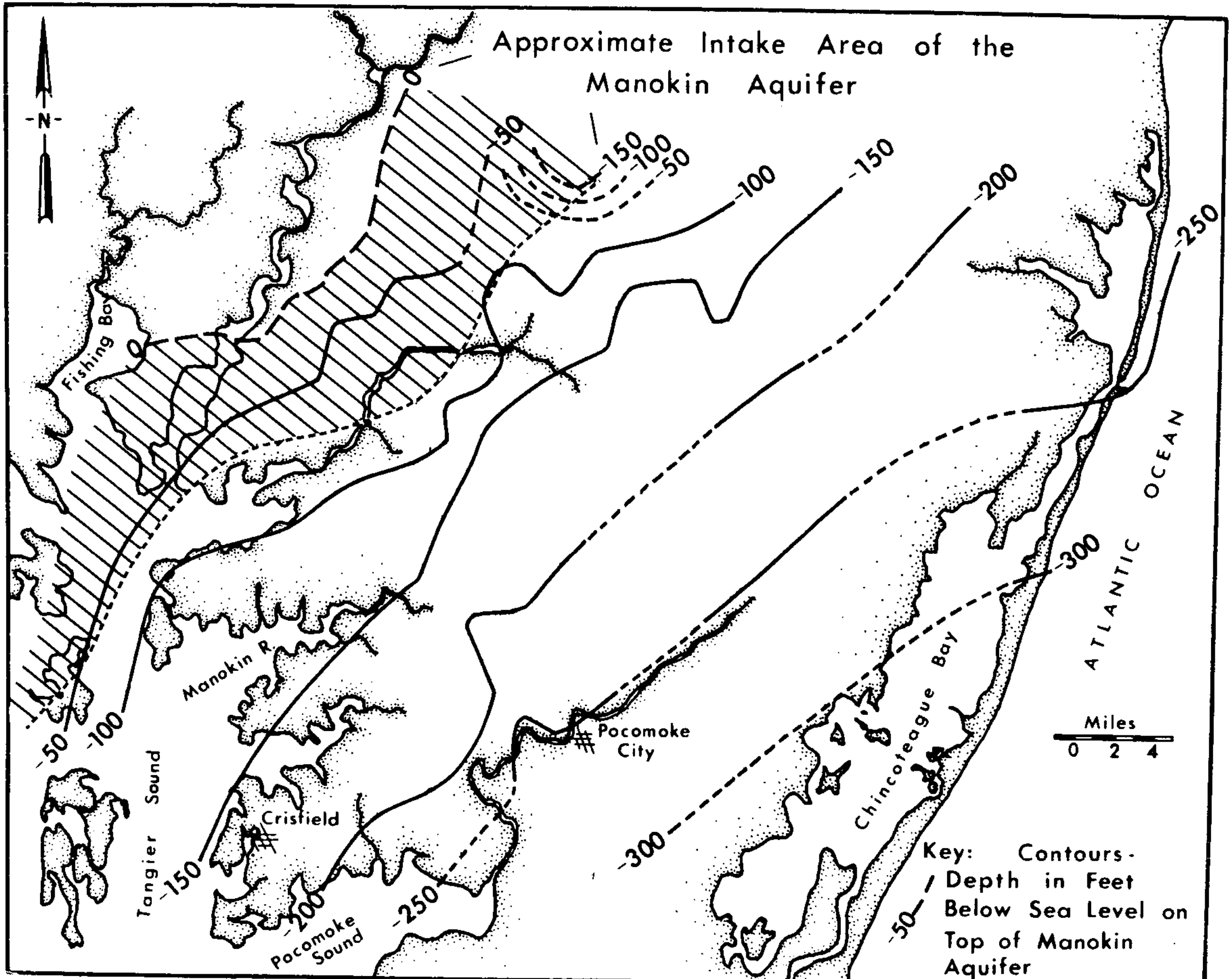

Figure 6. Approximate Intake Area of the Manokin Aquifer (After Rasmussen, 1955).

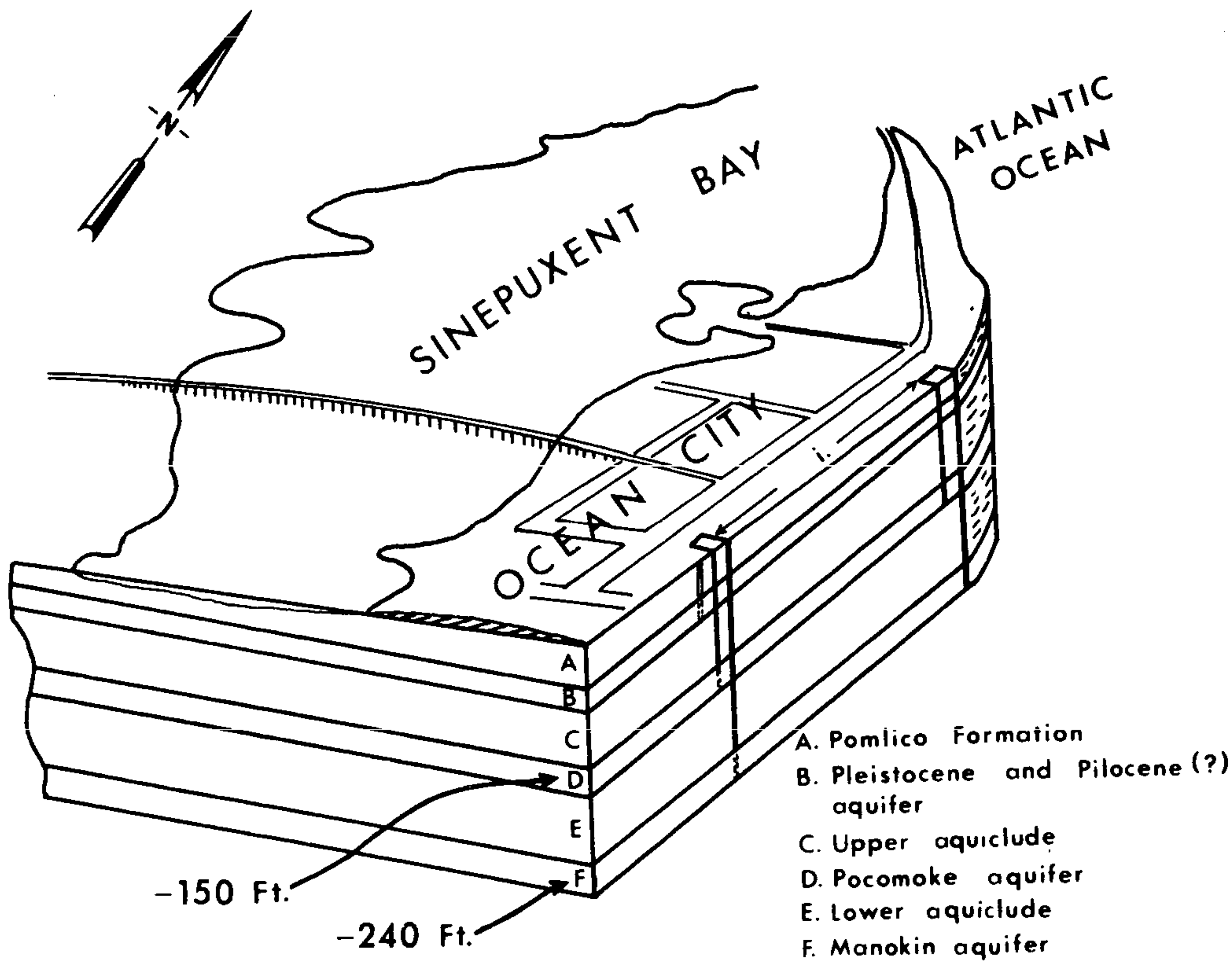

Figure 7. Aquifers Appearing Under Ocean City, Maryland (After Rasmussen, 1955).

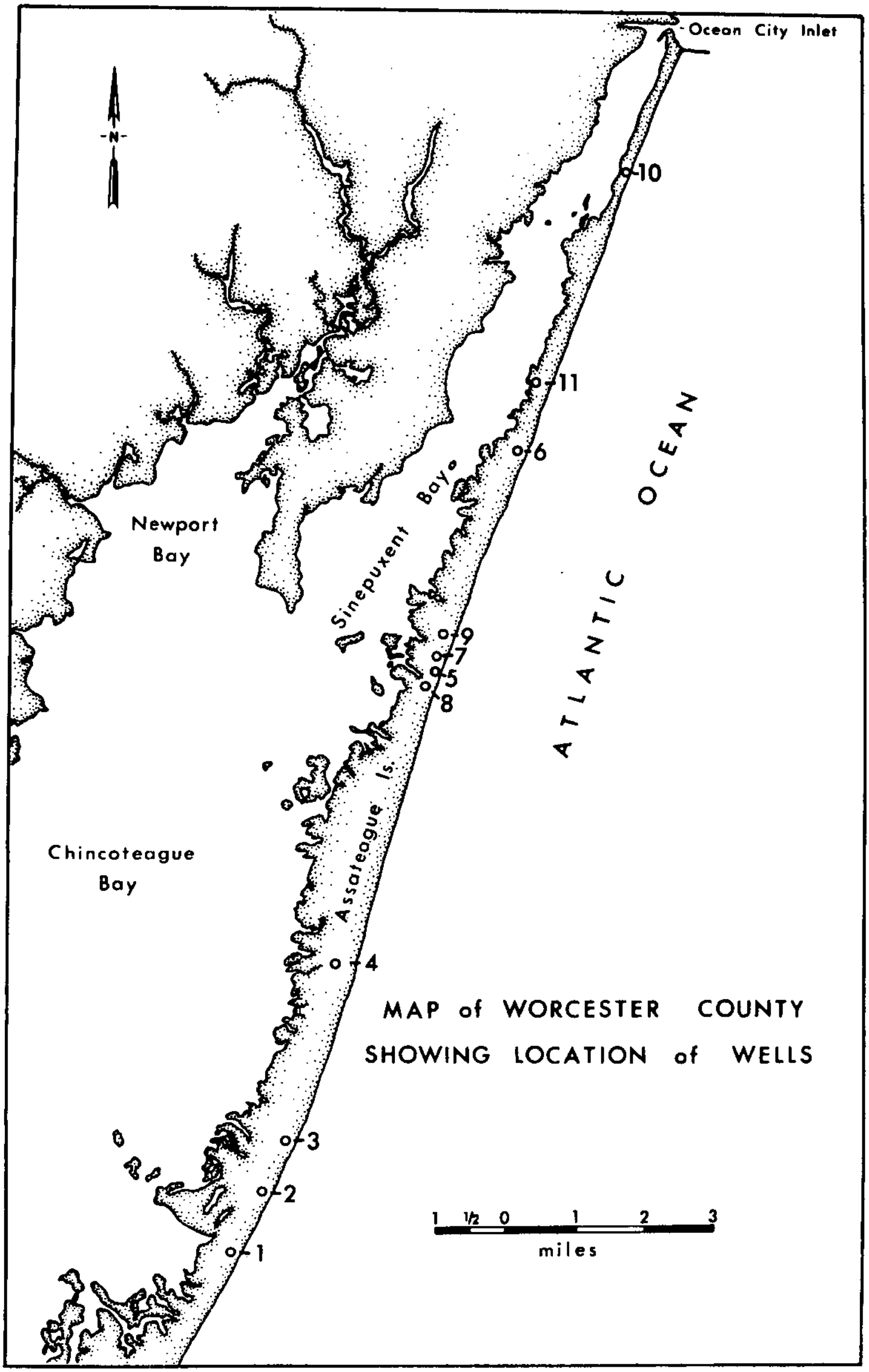

Figure 8. Wells on Assateague Island (After Rasmussen, 1955).

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C. Sedimentation in Chincoteague Bay

Charles E. Bartberger
and
Robert B. Biggs

SEDIMENTATION IN CHINCOTEAGUE BAY

Introduction

This section of the report will deal with the distribution of the types of surface sediments in Chincoteague Bay in relation to the sediment source areas and the climatic factors affecting sedimentation. An attempt will be made to evaluate the relative importance of the various source areas in supplying sediments to the bay.

The authors would like to acknowledge the work of Michael Veitch, Patricia O'Brien, and Walter Boynton, in performing the laboratory sediment analyses. The illustrations were done by Mrs. Frances Younger.

AVAILABLE DATA

Figure 1 is a map showing the generalized distribution of surface sediments in Chincoteague Bay from Ocean City Inlet to the Maryland-Virginia boundary. The map shows how the surface sediments are distributed based on the relative content of sand and mud. (Sand refers to any sedimentary particles between 2 mm and 0.624 mm in diameter; mud, which includes silt and clay, refers to all particles finer than 0.624 mm. One mm equals 0.04 inch.) The map is based on the size analysis of 91 sediment samples. Most of these samples were collected and sized by Chesapeake Biological Laboratory personnel, although some size data were taken from the work of Stout (1953). From the size analyses the percent of sand by weight was determined for each sediment sample. These values were plotted on the map. The sedimentary contours were then drawn.

The sediment distribution map (Figure 1) shows that the regions of different sand content form a belt-like pattern which parallels the shorelines of the Bay. Thus, it appears that the major variations in sediment grain size and sand content occur in an east-west direction across the width of the Bay. Sediment grain sizes and sand contents are highest along the margins of the Bay, and tend to decrease offshore toward the center of the Bay. Grain size and sand content tend to remain fairly uniform along any line trending northeast-southwest down the length of the Bay.

Figure 1 shows that almost all of the eastern shallow water portion of Chincoteague Bay bordering the marsh and back dune area of Assateague

Island is covered with sediment composed of 90% or more sand. These very sandy sediments extend westward into the Bay from Assateague Island for 1 to 2 miles (1.6-3.2 km) and also cover most of Sinepuxent Bay. Farther westward away from Assateague Island, the sand content of the sediment continues to decrease to a region of the Bay about one mile off the mainland shore where the percent of sand drops to less than 5%. It is in this western part of Chincoteague Bay that the finest grained sediments of the Bay occur. These sediments contain less than 20% sand (as low as 2% sand), and are predominantly composed of silt-sized particles. These fine-grained sediments are located in the deepest portion of the Bay. As the Bay becomes more shallow toward both the east and west, the sediments become progressively more coarse and contain more sand-sized particles. The only major variation to this sedimentary pattern occurs in Green Run Bay (see Figure 1) where finer grained sediments of relatively low sand content extend eastward close to the shoreline of Assateague Island. This wedge of finer sediments corresponds closely with a wedge-shaped region of noticeably deeper water in Green Run Bay, which can be seen on the United States Geological Survey topographic sheets and the United States Coast and Geodetic Survey Hydrographic Chart. This particular region of deeper water is probably the site of a former inlet which, when open, was scoured to a depth similar to the present inlets at Ocean City, Maryland, and Chincoteague, Virginia (Truitt, 1968; Gawne, 1966). Evidence confirming the existence of a major former inlet at this location is the occurrence of a thick local lens of unusually clean, silt-free sand to a depth of 20+ feet (6 m) encountered just behind Assateague Island during recent drilling operations (see Biggs, another section of this report).

DISCUSSION

Both the quantity and the type of sediment deposited in Chincoteague Bay are controlled largely by the winds, waves, tides, and rainfall. Coastal storms and hurricanes also have major effects upon sedimentation in Chincoteague Bay. The Bay receives sediments from Assateague Island, from erosion of the Bay shoreline, from streams entering the Bay from the mainland, and also probably through the Ocean City and Chincoteague Inlets.

The belt-like sediment distribution in Chincoteague Bay seems to reflect the location of the major source areas of sediments. They lie along the entire eastern and western margins of the Bay, rather than at the northern or southern extremities of the Bay. Furthermore, as coarser sediment particles tend to settle out of water more rapidly than finer ones, the coarsest sediments are located in the shallow portions of the Bay near the shorelines, while the finer grained sediments with lower sand contents are found in the deeper central part of the Bay. Although the importance of tidal currents in Chincoteague Bay is unknown, their effect, if any, in distributing sediment during both flooding and ebbing would be to move sediment in a northeast-southwest fashion, tending to maintain the belt-like sediment configuration.

Sources of Chincoteague Bay Sediments

(1) Barrier Island. The large quantities of sand in the eastern half of Chincoteague Bay are probably derived largely from Assateague Island, since the island contains the only large quantities of sand in the immediate vicinity of the Bay, and since sediment grain size in the Bay decreases westward from the island. The Bay, especially the eastern half, receives sediments from Assateague Island as easterly winds blow sand across the island, and as the sea washes over the island locally during storms and high water. For westward transport of sand by the wind into Chincoteague Bay from Assateague Island, the wind must be blowing onshore and the wind must have a source of sand available. Unlike the landward sides of most of the dunes on Assateague Island, which are stabilized by vegetation, the seaward sides of the dunes have loose sand faces susceptible to wind attack.

Consider, also, the way in which sand is carried by the wind. Laboratory studies, using high speed photography, show that each sand grain makes a long low leap carried by the wind, strikes the sand surface, and rebounds, continuing these leaps over and over again. Most of these leaps are quite low, being less than an inch or two off the sand surface (Strahler, 1966). Thus, any obstruction, such as salt marsh grass, would tend to inhibit the movement of sand by the wind.

There are only a few places along Assateague Island where dunes and/or sand flats lacking dense vegetation cover almost the entire width of the island from the ocean to the Bay. Such predominantly sandy areas occur along part of the island bordering the northern part of Sinepuxent Bay, and locally along the island at the heads of some of the longer guts which extend eastward into the back dune areas. Along most of the length of the barrier island, however, the western side of the island is bordered by a strip of salt marsh and/or bayberry vegetation about 1/4 to 1 mile (0.4-1.6 km) wide. These wide areas of relatively dense marsh and vegetative cover probably act as an effective barrier to sand transport across the island by wind.

The mean size of the sediment in one of the guts behind the Fox Hill Levels is about 0.48 mm,which is very similar to the mean size (0.44 mm) of the island beach sands. The sand deposited at the head of the guts was very likely carried into the Bay by a washover. From this point westward, the Bay sands show a progressive decrease in mean size. A similar pattern exists in the North Beach area near Great Egging Island, where intensive nearshore sampling was carried out. During storms and high water, as the island is washed over locally, the more coarse sand particles are deposited very soon after the washover water runs off the island, or out of a gut into the Bay. A washover current probably loses much of its velocity as soon as it empties into the Bay from its relatively narrow channel through the island. This sudden loss in current velocity would probably be accompanied by the immediate deposition of the coarsest sand particles.

An excellent view of the washover fans existing behind Assateague Island in the spring of 1967 can be seen on a set of U. S. Coast and Geodetic Survey aerial photographs taken on April 4, 1967. Washover fans extending over 1/2 mile (0.8 km) westward from the island into the Bay can be seen very clearly from Ocean City Inlet south to Green Run Bay. From Green Run Bay south, Assateague Island is considerably wider and contains many small interior ponds and bays such as Pope Bay, with a larger complex of small islands west of the main barrier island. Thus, washovers are probably not as common along this southern part of Assateague Island. Along the western side of Assateague Island from Ocean City inlet to Green Run Bay there are numerous guts and tidal creeks which head in or near the backdune areas of the island and have their mouths in the Bay. Most of these guts have washover fans at their mouths where they empty into the Bay.

To get a general feeling for the volume of sediment that may be deposited in Chincoteague Bay during one storm, consider the series of washover fans between Tingles Island and the Fox Hill Levels as seen on the set of aerial photographs. The washover fans cover a distance of about 4 miles (6.4 km) along this length of the island and extend about 3/8 mile (0.6 km) westward into the Bay, on the average. This is an area of about 1 1/2 square miles (3.8 km^2) of the Bay floor. Suppose this entire area of washover fans was receiving washover sediments during one particular storm, and that a 1-inch (2.5 cm) thickness of sediment was deposited over the entire area of the washover fans. This is not an unreasonable supposition, and is probably a rather conservative one. The volume of sediment deposited over this washover fan area would then be about 125,000 cubic yards (95,400 m^3). This is a 4-mile (6.4 km) stretch of the island. And considering that Assateague Island may be washed over along a distance two to three times the distance between Tingle Island and Fox Hill Levels, the total volume of sediment deposited in the Bay during one storm could be quite large.

Thus, it would appear that the bulk of the sand supplied to Chincoteague Bay by the barrier island is carried in by island washovers rather than by wind action. Winds are probably effective in blowing sand directly into the Bay in certain local areas where there is little or no vegetation behind the dune areas, especially along Sinepuxent Bay. Winds also continually blow sand up into the dune areas of the island where it is then susceptible to being carried back into the Bay during washovers. Also, once a washover has occurred and large quantities of sand are washed up locally onto the marshes behind the island, this sand will later dry out, and the loose, dry surficial sand can then be blown into the Bay. But considering the total volume of sediment supplied to the Bay from the barrier island, washovers rather than winds are probably more significant.

When waves approach a shoreline obliquely, they tend to produce both a beach drift and a longshore current which moves beach material along the shore in the same direction as that of wave approach (see Figure 2). The combined effect of beach drift and longshore current is called littoral drift. The magnitude of littoral drift which is determined by both the angle of approach and height of waves removes sand from a beach. It also continually supplies a beach with sand derived from beaches up-current. As long as rivers draining the continental mainland continue to supply sand to the sea, littoral drifting tends to maintain sand beaches in a state of dynamic equilibrium.

Waves approaching Assateague Island from the south or southeast would tend to cause a northerly littoral drift, whereas waves approaching from the east or northeast would tend to produce a southerly littoral drift. The overall yearly frequencies show that the predominant direction of wave approach is from the southeast, tending to cause a northerly littoral drift. There are no available records relating wave height to wave direction. However, in looking at the separate wave height and wave direction frequency records from the Ocean City, Maryland, lifeboat station (see Pellenbarg and Biggs, another section of this report), it is often true that the months with the highest surf also have a high frequency of northeasterly waves. Both the configuration of sand deposits on the northern and southern sides of the jetty at Ocean City inlet, and the nature of the hooked spit (Fishing Point) at the extreme southern end of Assateague Island indicate that the direction of net littoral drift along Assateague Island is southerly. Thus, the net southerly littoral drift is caused by a northeasterly wave approach along the shore of Assateague Island during high surf conditions.

(2) Shore Erosion within Chincoteague Bay. Erosion of the mainland shoreline and the island shorelines within Chincoteague Bay is another major source of sediment for the Bay. We have made a rough calculation of the volume of sediment supplied to the Bay each year by shoreline erosion. The calculation is based upon data from the Maryland Department of Geology, Mines, and Water Resources concerning shore erosion measurements in tidewater Maryland. The shore erosion measurements, some of which are included in Table 1, provide information about the number of acres of land lost by erosion and gained by deposition over an interval of about 90 years for all of the Maryland shoreline of Chincoteague Bay, including the Bay islands. The shorelines have been divided into a number of smaller regions, and for each segment of shoreline, a value for the annual rate of land loss or gain in acres per year is given (see Figure 3).

Knowing the rate of erosion in acres per year for a certain segment of shoreline and the height of the land, the volume of land lost by erosion can be determined. For each of eleven shoreline localities surrounding Chincoteague Bay, including the Bay islands, the average land height was estimated using USGS topographic maps (see Table 1). Knowing the land height and the rate of erosion in acres per year, the volume of land mass lost per year was calculated for each of the eleven shoreline localities (see Table 1 and Figure 3).

The regions showing the greatest rate of erosion are the islands in Martin and Purnell Bays, including Mills and Tizzard Islands, and the mainland shoreline of Chincoteague Bay from Newport Bay south to Martin Bay. Rates of loss in these regions range from .13 to .26 acres per mile per year (202-405 m^2 Km^{-1} yr^{-1}). The Bay islands and the mainland shoreline are continually exposed to the erosive action of waves in the Bay, and will probably continue to show a net loss of land area in the future.

However, the western side of Assateague Island shows a net gain of land area as the barrier island continues to migrate landward slowly. The region showing the greatest rate of gain (0.57 acres per mile per year, or 917 m^2 km^{-1} yr^{-1}) is between Ocean City inlet and latitude 38°-15' N, opposite the area showing the greatest net loss on the ocean shore. That the western side of Assateague Island is growing in land area attests to the fact that large quantities of washover and of wind-blown sand must be accumulating and building up tidal flats to a height where the salt marsh begins to take over.

While Assateague Island itself continues to grow westward, the islands neighboring the western shore of Assateague Island show a slight net loss of land area. They are probably more exposed to wave action, and, being farther from the ocean side of Assateague Island, receive smaller amounts of washover and wind-blown sand than does the western shoreline of Assateague Island.

Thus, while the western shoreline of Assateague Island grows westward, the mainland shoreline and the islands of Chincoteague Bay all undergo erosion, thereby supplying sediment to Chincoteague Bay. The total calculated volume of sediment supplied to Chincoteague Bay from shoreline erosion is about 33,560 cubic yards (25,500 m^3) per year.

(3) Sediment Runoff from Mainland Streams. The quantity of sediment entering Chincoteague Bay from streams draining the mainland is quite small. Most of the runoff from the Delmarva Peninsula in the vicinity of Chincoteague Bay flows into the Pocomoke River which empties into Chesapeake Bay. The drainage basin supplying runoff water to Chincoteague Bay is estimated to be about 75 square miles (195 km^2) in area, and the gradient of the small, sluggish tidal streams entering the Bay is quite low. The largest region of freshwater inflow is in the vicinity of Newport Bay (Pritchard, 1960). An estimate of the sediment yield for the Chincoteague Bay drainage area was obtained from Wolman and Schick (1967). They provide data about sediment yield for a number of small rural wooded drainage basins in Maryland for which the soil cover and yearly amount of rainfall are quite similar to the Chincoteague Bay region. Sediment yields for these comparable Maryland drainage basins range from 15 to about 500 tons per square mile, per year (5235-174,500 kg m^{-2} yr^{-1}).

Considering the low gradient, short length, and tidal nature of the streams entering Chincoteague Bay, and the nature of the unconsolidated, sandy soil of the area, a reasonable estimate of the sediment yield for the Chincoteague area might be about 50 tons per square mile per year (17,450 kg m^{-2} yr^{-1}). Since most of the sediment carried by these low gradient streams is probably silt and clay-size particles, the bulk density of the sediment is probably about 1.25 g cm^{-3} (Schubel, 1968). Therefore, one ton (907 kg) of the runoff sediment will occupy a volume of about 0.950 cubic yards (0.726 m^3). A sediment runoff of 50 tons per square mile, per year, for a drainage basin of 75 square miles will yield 3,750 tons, or about 3,561 cubic yards (2,722 m^3) of sediment per year. This figure is about one tenth of the 33,550 cubic yards (25,500 m^3) of sediment supplied by shore erosion. It should be kept in mind, however, that several storms accompanied by heavy rainfall in one year may cause the sediment yield from streams to be much higher. Nevertheless, the volume of sediment supplied by stream runoff would still be much less than that supplied by shoreline erosion and washovers from Assateague Island.

SUMMARY AND CONCLUSIONS

The surficial sediments of Chincoteague Bay are distributed in a belt-like pattern which parallels the shorelines of the Bay. This sediment distribution seems to reflect the location of the major source areas of sediments. The main sources of sediment lie along the entire eastern and western margins of the Bay rather than at the northern or southern ends of the Bay. As coarser sediment particles tend to settle out of water more rapidly than finer ones, the coarsest sediments are located in the shallow portions of the Bay near the shorelines, while the finer grained sediments with lower sand contents are found in the deeper central part of the Bay.

The occurrence of relatively fine sediment with low sand content just behind Assateague Island in Green Run Bay is probably related to the existence of a former inlet through Assateague Island. The zone of deep water behind the barrier island in Green Run Bay seems to be a remnant of a former inlet which, when open, was scoured to a depth similar to the present inlets at Ocean City, Maryland, and Chincoteague, Virginia. After the inlet was sealed off, sandy sediments blown westward by the wind and washed over the island during high water probably began being deposited in the locally deep water behind Assateague Island. The coarsest sediment settled out rapidly close to shore while the finer sediments were deposited farther and farther out into the Bay.

Chincoteague Bay receives sediments from Assateague Island, from erosion of the Bay shoreline, from streams entering the Bay from the mainland, and also probably through the Ocean City and Chincoteague inlets. Rough calculations of the volume of sediment supplied to the Bay by the various sources seem to indicate that Assateague Island is the major source of sediment for the Bay. The extensive areas of dense vegetation along most of the entire western side of Assateague Island, ranging from high cedar trees to low salt marsh, tend to inhibit the westward transport of sand into the Bay by the wind. Most of the sand supplied to the Bay from the barrier island probably is carried into the Bay during short periods of time, when the island is washed over locally in times of storms and high water. The estimate of about 125,000 cubic yards (95,400 m^3) of sediment supplied to the Bay by washovers during one storm along a 4-mile (6.4 km) stretch of the island is probably more than 4 times the amount of sediment contributed yearly to the Bay by shore erosion and stream inflow, together. Assateague Island may be washed over along a distance of 10 or 12 miles (16-18 km), so that the total volume of sediment deposited in the Bay during one storm could be large.

Although the estimate of the amount of sediment that may be contributed to the Bay by a single major storm is extremely rough, it seems quite reasonable to conclude that considerably more sediment is contributed to Chincoteague Bay by washovers from one major storm than by (1) wind action during an entire year, and (2) shore erosion and stream inflow during an entire year. Therefore, the catastrophic event of island washovers is probably the single most significant phenomenon affecting sedimentation in Chincoteague Bay.

TABLE 1. SHORE EROSION STATISTICS FOR MARYLAND PORTION OF CHINCOTEAGUE BAY. (DATA PARTIALLY TAKEN FROM STATE OF MARYLAND DEPT. OF GEOLOGY, MINES, AND WATER RESOURCES BULLETIN 6, 1949).

	Locality	Time Interval Years	Miles Of Shoreline Measured	Acres Lost Per Mile Per Year.	Ave. Land Height (Ft.)	Vol. Lost Per Mile Per Year (Cu. Yards)	Total Vol. Lost Over Shoreline Per Year (Cu. Yards)	Total Vol. Lost Over Shoreline Per Year (Cu. M.)
I.	Sinepuxent Bay-East Shore Ocean City Inlet to Latitude 38° 15' N.	92	8.5	0.57*	1.5	1,379.4	11,724.9*	8,964.9*
II.	Lower Sinepuxent & Upper Chincoteague Bay-East Shore, Latitude 38° 15' N. to 38° 07' 30" N.	93	23.3	0.16*	1.5	387.2	9,021.8*	6,898.0*
III.	Chincoteague Bay-East Shore, Latitude 38° 07' 30" N. to Md.-Va. Boundary	92	19.7	0.18*	1.5	435.6	8,581.3*	6,561.3*
IV.	Sinepuxent Bay-West Shore Ocean City Dredged Harbor Slip to Sandy Point.	93	8.5	0.07	3.5	395.2	3,359.8	2,508.9
V.	Sinepuxent Bay-West Shore, Sandy Point to South Point.	93	5.1	0.09	5	726.0	3,702.6	2,831.0
VI.	Newport Bay	92	7.7	0.18	4	1,161.6	8,944.3	6,838.8
VII.	Chincoteague Bay-West Shore, Handys Hammock to Tanhouse Creek.	92	8.3	0.18	2	580.8	4,820.6	3,685.9
VIII.	Chincoteague Bay-West Shore, Tanhouse Creek to Martin Bay.	92	22.4	0.13	3	629.2	1,510.1	1,154.6
IX.	Chincoteague Bay-West Shore-Martin Bay to Md.-Va. Boundary.	92	12.9	0.06	2	193.6	2,497.7	1,909.5
X.	Martin to Purnell Bay Islands.	92	10.9	0.26	1.5	629.2	6,858.3	5,243.8
XI.	Islands Neighboring Western Shore of Assateague Island.	93	24	0.03	1.5	77.4	1,858.6	1.421.1
	TOTAL VOLUME OF SEDIMENT LOST PER YEAR TO MARYLAND PORTION OF CHINCOTEAGUE BAY.					--	33,551.7	25,653.6

* Indicates Gain.

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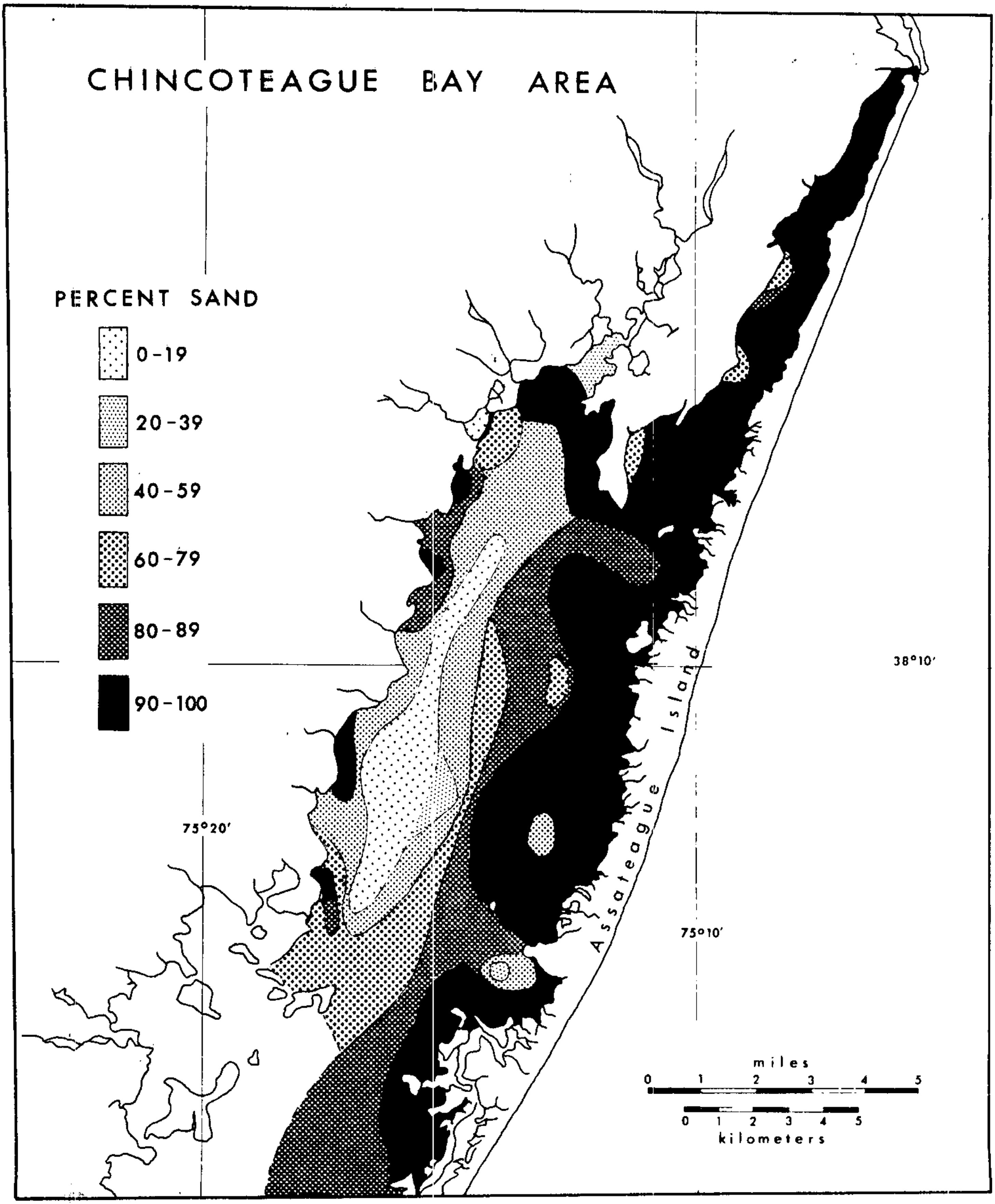

Fig. 1 Distribution of surface sediments in Chincoteague Bay based on sand content.

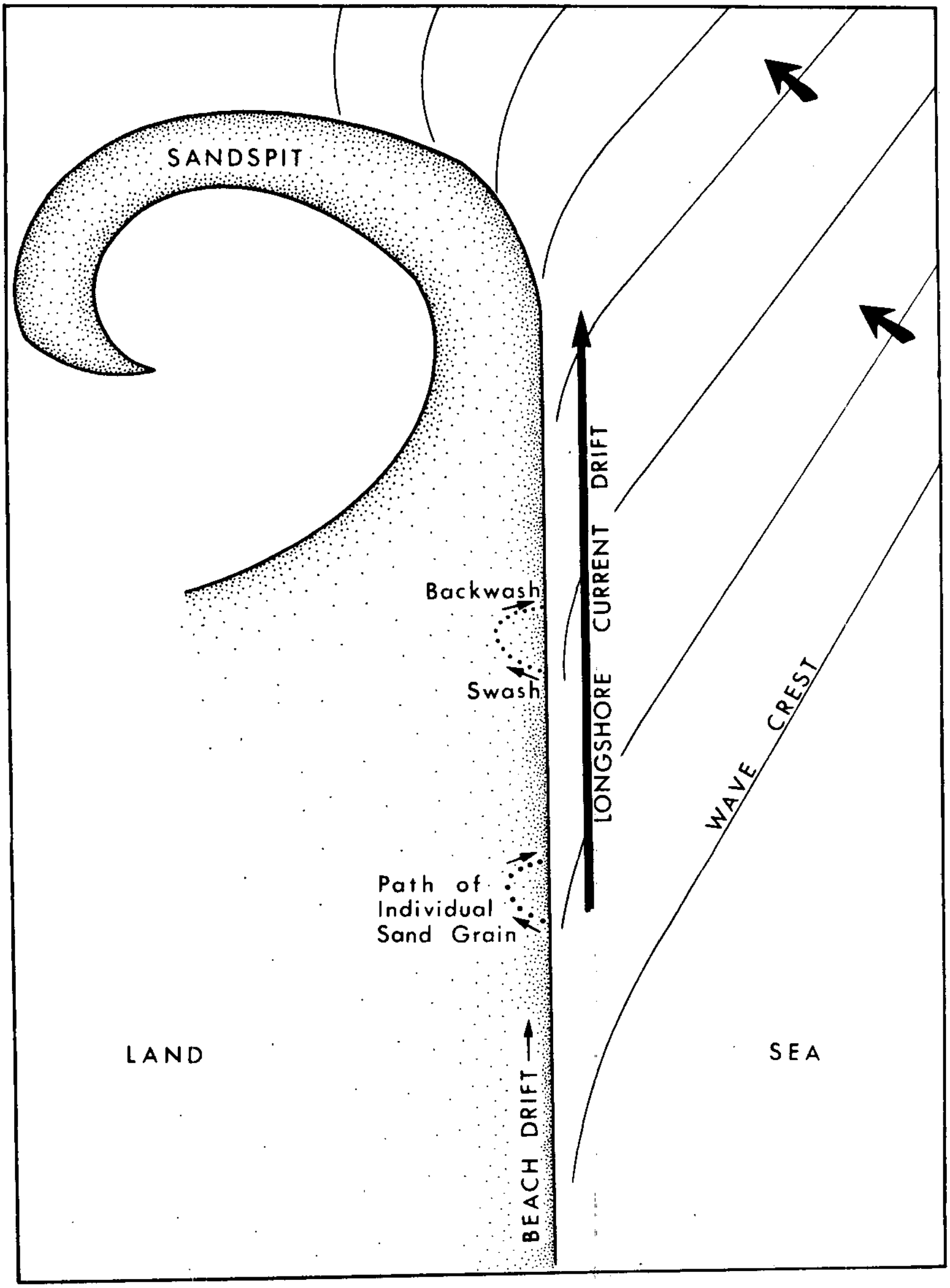

Figure 2. Sketch map showing how the oblique approach of waves against a sand beach causes sand to be transported in the same direction by beach drifting and longshore current drifting. (modified from Strahler, 1966).

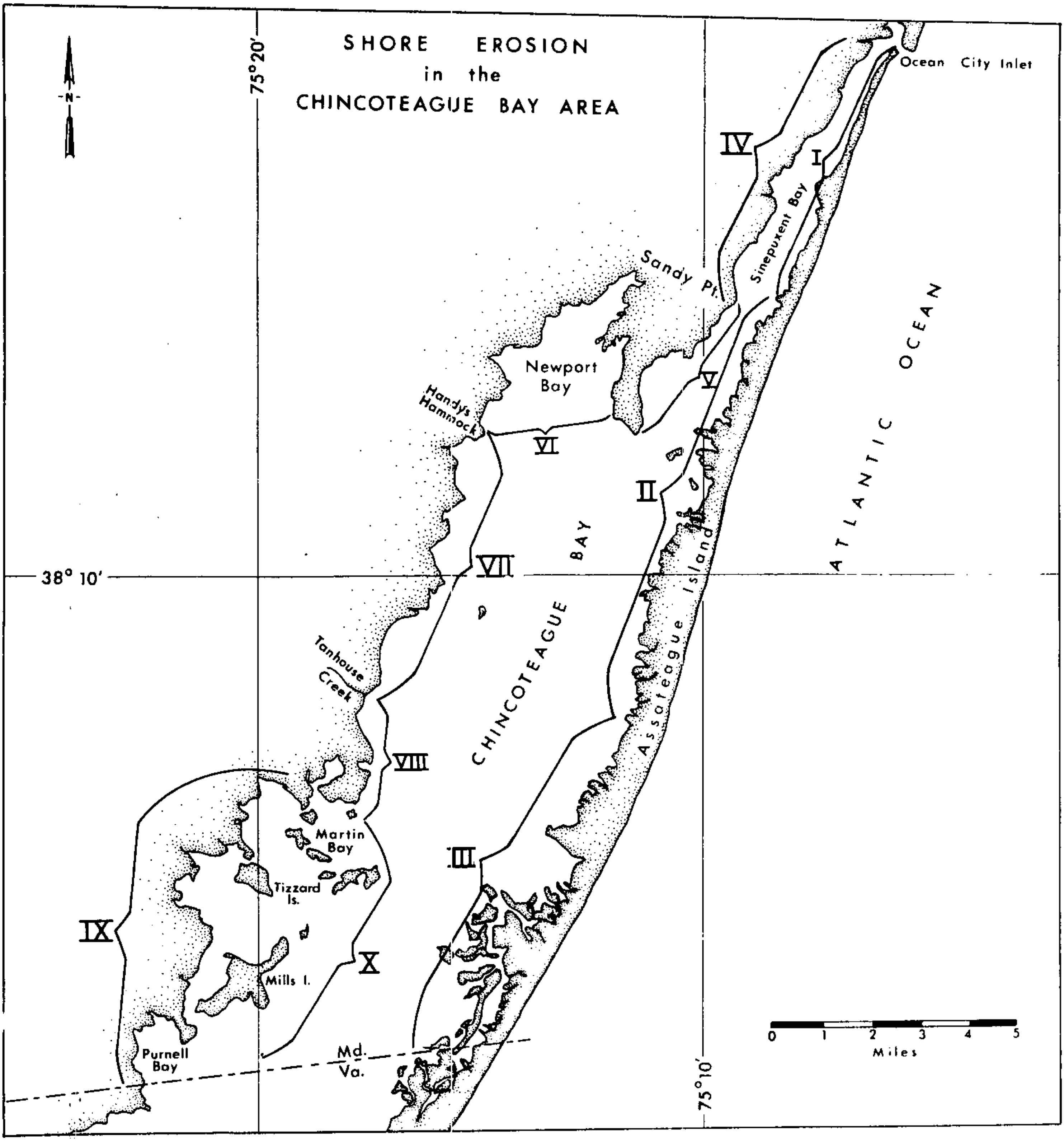

Figure 3. Map Showing Shoreline Erosion Localities Listed in Table 1.